



Occidental Chemical Corporation

SDMS Document



112851

**FEASIBILITY STUDY
FOR OPERABLE UNIT - 3**

**VINYL CHLORIDE SUBPLUME IN THE VICINITY OF MW-52
HICKSVILLE, NEW YORK**

PRINTED ON

JUL 25 2000

400042



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION 2
290 BROADWAY
NEW YORK, NY 10007-1866

The OU-3 Feasibility Study for Operable Unit-3 for the Hooker Ruco Site has been approved with the following changes:

General Comments

- 1) The text in the first paragraph of page 2 specifying OXY's belief that "that the downgradient edge of the VCM subplume is the maximum areal extent to which chemicals from the Hooker/Ruco Site may have migrated" is inappropriate and should be ignored.

Specific comments:

1 Figures 3.1 and 3.2:

Figure 3.1, 4.1, 4.3, 4.5, 4.6, 4.7 and 4.8 of the FS have not accurately depicted TCE/PCE plume.

2 Page 42, Enhanced Bioremediation, First Paragraph:

Anaerobic bioremediation of chlorinated organics from 1,2 dichloroethylene (1,2-DCE) to vinyl chloride has not been demonstrated and appears to be a rate limiting step with respect to anaerobic respiration for the Long Island aquifer. This is based on groundwater analytical results. Therefore, the mature PCE and TCE plumes are being reduced by anaerobes (dehalorespirers) to 1,2-DCE, are apparently stopping there, in lieu of being converted to innocuous compounds, as the text suggests. However, the FS screens out anaerobic bioremediation later in the text. For the record, this letter serves to document this.

3 Page 44, Enhanced Anaerobic Biodegradation, Effectiveness):

Anaerobic rates are not necessarily an order of magnitude slower than aerobic rates and it is inappropriate to make statements made in the FS on page 44 such as "rates are an order of magnitude slower" without providing a definitive reference (which does not exist for this particular statement.) This problem can be eliminated by revising the 2nd and 3rd sentences of the new text to be read as following:

"Once appropriate conditions are established, the degradation half-lives for anaerobic degradation are typically measured in weeks to months."

4) Page 107, Section 5.2.4.3, Long-term^{1/4}, 2nd sentence):

In the parenthetical, TCE should be included with PCE. There is no reason to suspect that TCE will be affected by biodegrading without addition of a cosubstrate. The meaning of the phrase "to a lesser degree" that was added with TCE is not clear, and the phrase is not necessary, so it should be removed. This also applies to the bottom of page 104.



Occidental Chemical Corporation

**FEASIBILITY STUDY
FOR OPERABLE UNIT - 3**

**VINYL CHLORIDE SUBPLUME IN THE VICINITY OF MW-52
HICKSVILLE, NEW YORK**

JULY 2000

REF. NO. 6883 (18)

This report is printed on recycled paper.

400045

TABLE OF CONTENTS

| | <u>Page</u> |
|---|-------------|
| 1.0 INTRODUCTION | 1 |
| 1.1 PURPOSE OF REPORT | 1 |
| 1.2 OBJECTIVE AND SCOPE | 2 |
| 1.3 REPORT ORGANIZATION | 3 |
| 1.4 ACKNOWLEDGMENTS | 3 |
| 2.0 HISTORICAL INFORMATION | 4 |
| 2.1 SITE DESCRIPTION | 4 |
| 2.2 SITE HISTORY | 4 |
| 2.3 SITE OPERATIONS | 4 |
| 2.4 WASTEWATER DISPOSAL PRACTICES | 5 |
| 2.5 MUNICIPAL PUMPING CENTERS | 5 |
| 2.6 HYDROGEOLOGIC SETTING | 7 |
| 2.7 PREVIOUS INVESTIGATIONS | 7 |
| 2.8 SUMMARY | 9 |
| 3.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES | 10 |
| 3.1 INTRODUCTION | 10 |
| 3.2 REMEDIAL ACTION OBJECTIVES | 10 |
| 3.2.1 MEDIA OF CONCERN | 10 |
| 3.2.2 PATHWAYS OF EXPOSURE | 11 |
| 3.2.3 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARS) | 11 |
| 3.2.3.1 CHEMICAL-SPECIFIC ARARS AND TBCS | 13 |
| 3.2.3.2 LOCATION-SPECIFIC ARARS AND TBCS | 16 |
| 3.2.3.3 ACTION-SPECIFIC ARARS AND TBCS | 17 |
| 3.2.4 REMEDIAL ACTION OBJECTIVES | 23 |
| 3.2.5 PRELIMINARY REMEDIAL ACTION GOALS | 23 |
| 3.2.6 AMBIENT AIR QUALITY ARARS | 23 |
| 3.3 GENERAL RESPONSE ACTIONS | 24 |
| 3.3.1 VOLUMES FOR TREATMENT | 24 |
| 3.3.2 GENERAL RESPONSE ACTIONS | 25 |
| 3.4 IDENTIFICATION AND SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS | 26 |
| 3.4.1 INITIAL SCREENING OF TECHNOLOGIES/PROCESS OPTIONS | 26 |
| 3.4.2 SUMMARY OF INITIAL SCREENING OF TECHNOLOGIES/PROCESS OPTIONS | 26 |
| 3.4.3 EVALUATION CRITERIA FOR DETAILED SCREENING OF TECHNOLOGIES | 27 |
| 3.4.4 DETAILED SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS | 28 |

| | | |
|---------|---|----|
| 3.4.4.1 | NO FURTHER ACTION - NORTHROP IRM (NO VCM TREATMENT)..... | 28 |
| 3.4.4.2 | ENHANCED NORTHROP IRM/ SUPPLEMENTAL VCM TREATMENT (IF NECESSARY)..... | 29 |
| 3.4.4.3 | GROUNDWATER REMOVAL | 30 |
| 3.4.4.4 | GROUNDWATER TREATMENT..... | 31 |
| 3.4.4.5 | GROUNDWATER DISCHARGE TECHNOLOGIES..... | 34 |
| 3.4.4.6 | IN SITU TREATMENT | 36 |
| 3.4.4.7 | IN SITU DELIVERY SYSTEM..... | 45 |
| 3.4.4.8 | SUMMARY OF FINAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS - GROUNDWATER | 47 |
| 3.4.4.9 | SELECTION OF REPRESENTATIVE PROCESS OPTIONS | 47 |
| 4.0 | DEVELOPMENT AND DESCRIPTION OF REMEDIAL ACTION ALTERNATIVES..... | 49 |
| 4.1 | RATIONALE FOR DEVELOPMENT OF ALTERNATIVES..... | 50 |
| 4.2 | DESCRIPTION OF ALTERNATIVES | 50 |
| 4.2.1 | ALTERNATIVE 1: NO FURTHER ACTION - NORTHROP IRM (NO VCM TREATMENT)..... | 51 |
| 4.2.2 | ALTERNATIVE 2: ENHANCED NORTHROP IRM (SUPPLEMENTAL VCM TREATMENT IF NECESSARY)..... | 53 |
| 4.2.3 | ALTERNATIVES 3A AND 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE..... | 55 |
| 4.2.3.1 | ALTERNATIVE 3A: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE FOR VCM MASS REDUCTION | 55 |
| 4.2.3.2 | ALTERNATIVE 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE TO ACHIEVE GROUNDWATER ARARS | 61 |
| 4.2.4 | IN SITU TREATMENT OF VCM SUBPLUME | 62 |
| 4.2.4.1 | ALTERNATIVE 4A: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION | 64 |
| 4.2.4.2 | ALTERNATIVE 4B: IN SITU TREATMENT OF VCM SUBPLUME BY CHEMICAL OXIDATION | 66 |
| 4.2.4.3 | ALTERNATIVE 4C: IN SITU TREATMENT OF VCM SUBPLUME BY BIOSPARGING..... | 68 |
| 5.0 | DETAILED ANALYSIS OF ALTERNATIVES..... | 70 |
| 5.1 | INTRODUCTION | 70 |
| 5.1.1 | EVALUATION CRITERIA | 70 |
| 5.1.2 | RELATIVE IMPORTANCE OF CRITERIA | 73 |
| 5.1.3 | SELECTION OF REMEDY | 74 |
| 5.2 | DETAILED ANALYSIS | 75 |
| 5.2.1 | ALTERNATIVE 1: NO FURTHER ACTION - NORTHROP IRM (NO VCM TREATMENT) | 75 |
| 5.2.2 | ALTERNATIVE 2: ENHANCED NORTHROP IRM (SUPPLEMENTAL VCM TREATMENT IF NECESSARY)..... | 78 |

| | | |
|---------|--|-----|
| 5.2.3 | ALTERNATIVES 3A AND 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE..... | 82 |
| 5.2.3.1 | ALTERNATIVE 3A: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE FOR VCM MASS REDUCTION..... | 83 |
| 5.2.3.2 | ALTERNATIVE 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE TO ACHIEVE GROUNDWATER ARARS | 88 |
| 5.2.4 | ALTERNATIVES 4A, 4B, AND 4C: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION/CHEMICAL OXIDATION/ BIOSPARGING FOR VCM MASS REDUCTION..... | 92 |
| 5.2.4.1 | ALTERNATIVE 4A: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION | 92 |
| 5.2.4.2 | ALTERNATIVE 4B: IN SITU TREATMENT OF VCM SUBPLUME BY CHEMICAL OXIDATION | 96 |
| 5.2.4.3 | ALTERNATIVE 4C: IN SITU TREATMENT OF VCM SUBPLUME BY BIOSPARGING..... | 101 |
| 6.0 | COMPARATIVE ANALYSIS..... | 107 |
| 6.1 | OVERALL PROTECTION OF HUMAN HEALTH AND ENVIRONMENT | 107 |
| 6.2 | COMPLIANCE WITH ARARS AND TBCS..... | 108 |
| 6.3 | LONG-TERM EFFECTIVENESS AND PERMANENCE..... | 108 |
| 6.4 | REDUCTION OF TOXICITY, MOBILITY, AND VOLUME | 109 |
| 6.5 | SHORT-TERM EFFECTIVENESS | 109 |
| 6.6 | IMPLEMENTABILITY | 110 |
| 6.7 | COST | 111 |

LIST OF FIGURES
(Following Report)

| | |
|------------|---|
| FIGURE 1.1 | SITE LOCATION |
| FIGURE 3.1 | VCM SUBPLUME-PLAN VIEW |
| FIGURE 3.2 | VCM SUBPLUME - CROSS-SECTION |
| FIGURE 4.1 | ALTERNATIVES 1 & 2 - NORTHROP IRM - EXTRACTION WELL LOCATIONS |
| FIGURE 4.2 | ALTERNATIVES 2, 3A, 3B, 4A, & 4B VCM MONITORING WELL LOCATIONS |
| FIGURE 4.3 | ALTERNATIVES 3A & 3B - PROPOSED EXTRACTION WELL LOCATIONS - PLAN VIEW |
| FIGURE 4.4 | ALTERNATIVES 3A & 3B - PROPOSED EXTRACTION WELL LOCATIONS - CROSS-SECTION |
| FIGURE 4.5 | ALTERNATIVES 3A & 3B - PROPOSED MONITORING WELL LOCATIONS VCM EXTENT CONFIRMATION |
| FIGURE 4.6 | ALTERNATIVES 3A & 3B -PROPOSED TREATMENT FACILITY LOCATION |
| FIGURE 4.7 | ALTERNATIVES 4A & 4B - PROPOSED INJECTION LOCATIONS FOR IN SITU REMEDIATION |
| FIGURE 4.8 | ALTERNATIVE 4C - PROPOSED INJECTION LOCATIONS FOR IN SITU REMEDIATION |

LIST OF TABLES
(Following Report)

| | |
|-----------|--|
| TABLE 2.1 | CALCULATED RISKS FOR FUTURE AREA RESIDENTS |
| TABLE 3.1 | FEDERAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS |
| TABLE 3.2 | NEW YORK STATE APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS |
| TABLE 3.3 | ARARs/TBCs FOR GROUNDWATER CHEMICALS OF CONCERN |
| TABLE 3.4 | INITIAL IDENTIFICATION AND SCREENING OF TECHNOLOGIES/PROCESS OPTIONS (GENERAL APPLICABILITY) FOR GROUNDWATER TREATMENT |
| TABLE 3.5 | SUMMARY OF COMPARATIVE TECHNOLOGY SCREENING FOR SITE GROUNDWATER |

LIST OF APPENDICES

| | |
|------------|--|
| APPENDIX A | HYDROGEOLOGIC MODELING |
| APPENDIX B | ALTERNATIVE COST SUMMARY TABLES |
| APPENDIX C | MASS FLUX ESTIMATES OU-1 GROUNDWATER CONTRIBUTIONS TO OU-3 GROUNDWATER |
| APPENDIX D | RESULTS OF LITERATURE SEARCH ON CHEMICAL OXIDATION |
| APPENDIX E | NASSAU COUNTY GROUNDWATER DATA |

LIST OF ACRONYMS

| | |
|------------------|---|
| ARAR | Applicable or Relevant and Appropriate Requirements |
| BDAT | Best Demonstrated Available Technology |
| BGS | below ground surface |
| BWD | Bethpage Water District |
| CAA | Clean Air Act |
| CAMU | Corrective Action Management Unit |
| CRA | Conestoga-Rovers & Associates |
| CSFs | Cancer Slope Factors |
| CWA | Clean Water Act |
| DOT | Department of Transport |
| ECL | Environmental Conservation Law |
| EPA | U.S. Environmental Protection Agency |
| FS | Feasibility Study |
| GSHI | Glenn Springs Holdings, Inc. |
| Hooker/Ruco Site | Hooker Chemical/Ruco Polymer Superfund Site |
| IRIS | Integrated Risk Information System |
| IRM | Interim Remedial Measure |
| LDR | Land Disposal Restrictions |
| LOAEL | lowest-observed-adverse effect level |
| MCLG | Maximum Contaminant Level Goals |
| MCLs | Maximum Contaminant Levels |
| MF | modifying factor |
| NAAQs | National Ambient Air Quality Standards |
| Navy | Naval Weapons Industrial Reserve Plant |
| NCDOH | Nassau County Department of Health |
| NCP | National Contingency Plan |
| NEPA | National Environmental Policy Act |
| NESHAPs | National Emissions Standards for Hazardous Air Pollutants |
| NOAEL | no-observed-adverse effect level |
| Northrop | Northrop Grumman Aerospace Corporation |
| NSPS | New Source Performance Standards |
| NYSDEC | New York State Department of Environmental Conservation |
| O&M | Operation and Maintenance |
| ORD | Office of Research and Development |

LIST OF ACRONYMS

| | |
|----------------|--|
| OxyChem | Occidental Chemical Corporation |
| OU-1 | Operable Unit - 1 |
| OU-3 | Operable Unit - 3 |
| OU-3 RI Report | Final Remedial Investigation Report, Operable Unit - 3, July 2000 |
| PCE | tetrachloroethene |
| POC | principal organic contaminant |
| POTW | Publicly Owned Treatment Works |
| PRGs | Preliminary Remedial Action Goals |
| PRP | Potentially Responsible Party |
| PSD | Prevention of Significant Deterioration |
| PVC | polyvinyl chloride |
| RAOs | Remedial Action Objectives |
| RA Report | Revised Final Risk Assessment and Fate and Transport Report, Operable Unit 1, October 1992 |
| RfD | Reference Dose |
| RGFS | Regional Groundwater Feasibility Study |
| RI | Remedial Investigation |
| RME | reasonable maximum exposure |
| SDWA | Safe Drinking Water Act |
| SIP | State Implementation Plan |
| SPDES | State Pollution Discharge Elimination Permit |
| SVOC | semi-volatile organic compound |
| TAGM | Technical and Administrative Guidance Memorandum |
| TBC | To Be Considered |
| TCE | trichloroethene |
| TCL | Target Compound List |
| TCLP | Toxicity Characteristic Leaching Procedure |
| TICs | Tentatively Identified Compounds |
| UCL | upper confidence limit |
| UF | uncertainty factor |
| UOC | unspecified organic contaminant |

LIST OF ACRONYMS

| | |
|----------------|--|
| VCM | vinyl chloride monomer |
| VOC | volatile organic compound |
| VPGAC | Vapor Phase Granular Activated Carbon |
| 1992 RI Report | Draft Remedial Investigation Report, Hooker/Ruco Site, April 1990 (Revised August 1992) |

1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

This Feasibility Study (FS) has been prepared by Conestoga-Rovers & Associates (CRA) on behalf of Occidental Chemical Corporation (OxyChem) and Glenn Springs Holdings Inc. (GSHI), to address the vinyl chloride monomer (VCM) groundwater subplume in the area of well MW-52, located south of the Hooker Chemical/Ruco Polymer Superfund Site (Hooker/Ruco Site), in Hicksville, New York. The Hooker/Ruco Site location is shown on Figure 1.1. OxyChem is a Potentially Responsible Party (PRP) for the Hooker/Ruco Site.

The regional groundwater aquifer in the area of the VCM subplume contains chemicals from three contingent sites, the Hooker/Ruco Site, the Northrop Grumman Aerospace Corporation (Northrop) Site, and the Naval Weapons Industrial Reserve Plant (Navy). Previous investigations by OxyChem, Northrop and the Navy have identified a volatile organic compound (VOC) plume in the regional groundwater which contains chemicals attributable to the three sites, as well as other sources upgradient of the three sites. In addition, recently obtained groundwater results from Nassau County show extensive PCE and TCE presence west of the Hicksville wells indicating other unknown sources for PCE and TCE to the regional aquifer. The chemicals from the various sources have intermingled to varying degrees. Within the regional VOC plume, a VCM subplume has been identified in the area of monitoring well nest MW-52, which is located in the northwest portion of the regional VOC plume. The area in the vicinity of the VCM presence has been designated as Operable Unit - 3 (OU-3) for the Hooker/Ruco Site.

OxyChem has performed a series of investigations to assist in defining the nature and extent of chemical presence in the northwest portion of the VOC plume, as its contribution to the regional VOC plume remedy.

The results of the OxyChem investigations are presented in the reports entitled:

- Draft Remedial Investigation Report, Hooker/Ruco Site, April 1990 (Revised August 1992) (1992 RI Report);
- Final Remedial Investigation Report, Operable Unit - 3, July 2000 (OU-3 RI Report);
- Groundwater Laboratory Treatability Study Report, Hooker Chemical/Ruco Polymers Superfund Site", July 1999 (Treatability Study Report); and
- Predesign Investigation Report for Operable Unit - 1, Hooker Chemical/Ruco Polymers Superfund Site, April 1999 (OU-1 Predesign Report).

The investigations showed that the VCM subplume is a small portion of the regional VOC plume, comprising only approximately 1.7 percent of the total VOC volume. In addition to completing the above investigations, OxyChem has been requested to complete this FS for the VCM subplume by the U.S. Environmental Protection Agency (EPA), as part of its ongoing contribution to the regional VOC plume remedy.

A separate FS is being prepared by the Navy and Northrop, and reviewed by the New York State Department of Environmental Conservation (NYSDEC) to address the regional VOC groundwater plume. A draft of the document entitled "Groundwater Feasibility Study, Gruman Aerospace - Bethpage, New York Site (#130003A) and Naval Weapons Industrial Reserve Plant, Bethpage, New York Site (#13000313)" (RGFS) dated February 25, 1999 has been prepared and a revised version submitted on December 17, 1999.

Northrop has implemented an interim remedial measure (IRM) to address the portion of the regional plume located upgradient of the southern boundary of the Northrop site. The portion of the VOC plume downgradient of the southern boundary of the Northrop site is addressed by bioremediation and treatment plants which have been constructed at the downgradient municipal wells.

Computer simulations show that the Northrop IRM fully contains the VCM subplume. Thus, any remedial actions that would be implemented by OxyChem to address the VCM subplume as a separate entity would be an enhancement to an already effective remedy.

1.2 OBJECTIVE AND SCOPE

The objective of this FS is to develop, evaluate, and select potential remedial alternatives that can be implemented to protect human health and the environment from risks associated with the groundwater containing elevated VCM presence in the MW-52 well area as well as any other chemicals in the area that are attributable to the Hooker/Ruco Site. As discussed in the OU-3 RI Report, OxyChem believes that the downgradient edge of the VCM subplume is the maximum areal extent to which chemicals from the Hooker/Ruco Site may have migrated, although the EPA may not agree with this statement. None the less, for the purposes of this FS, reference to the VCM subplume is intended to include all of the chemicals within the VCM subplume that are attributed to the Hooker/Ruco Site.

This study is based on the information collected by the Navy, Northrop and OxyChem field investigations. These investigations showed the chemical concentration levels and the extent of the plumes in the regional groundwater. The chemicals present were predominantly VOCs, and to a minor extent semi-volatile organic compounds (SVOCs) and inorganics. Implementation of a remedy that addresses the VOC presence in the groundwater will also address the SVOCs and inorganics.

1.3 REPORT ORGANIZATION

Section 2.0 presents historical information for the Hooker/Ruco Site as well as applicable regional data. Section 3.0 presents a discussion of the remedial action objectives including the preliminary remedial action goals, the general response actions, and a screening and selection of remedial technologies and process options. Section 4.0 presents the development and screening of the alternatives. Alternatives are described in some detail based on conceptual designs of the remedial actions. Section 5.0 presents a detailed analysis and a comparison between alternatives using the National Contingency Plan (NCP) criteria. Section 6.0 presents the conclusions and recommendations of the FS.

1.4 ACKNOWLEDGMENTS

Certain sections of this FS were obtained from the report entitled "Regional Groundwater Feasibility Study" (RGFS). OxyChem and GSHI hereby express their gratitude to the Navy, Northrop, and Arcadis Geraghty & Miller for the use of this information.

2.0 HISTORICAL INFORMATION

2.1 SITE DESCRIPTION

The Hooker/Ruco Site is a 14-acre active polymer manufacturing facility located in a heavily industrialized section of Hicksville, New York, as shown on Figure 1.1. The Hooker/Ruco Site is bounded immediately to the west and south by New South Road and the Long Island Railway, respectively. South Oyster Bay Road is located approximately 800 feet east of the Hooker/Ruco Site. A comprehensive site description including historical wastewater disposal practices, is provided in the OU-3 RI Report.

2.2 SITE HISTORY

The Hooker/Ruco Site was developed by Rubber Corporation of America, a small privately held company. Operations at the Hooker/Ruco Site began in 1945 and included natural rubber latex storage, concentrating, and compounding. Five years later, the plant began producing small volumes of plasticizers. These activities were expanded and modified through the years. In 1956, a polyvinyl chloride (PVC) plant was built, and was initially operated under the name Insular Chemical Corporation. The plant continued in operation until 1975. Hooker Chemical Corporation purchased Rubber Corporation of America in 1965, and operated the facility as the Ruco Division. Hooker has undergone several name changes, with the current name being OxyChem. The facility was sold to Ruco employees in February 1982. Thus, OxyChem or the Rubber Corporation of America owned and operated the Site between 1945 and 1982. After 1982, the Hooker/Ruco Site was operated by a privately held corporation under the name Ruco Chemical Corporation, which is not affiliated with OxyChem. In 1998, the name changed to Ruco Polymers, a subsidiary of Sybron Chemicals, Inc. Although OxyChem did not lease any portion of the Hooker/Ruco Site to third parties, there was an office building for the plant, which was housed in a leased building north of the Hooker/Ruco Site.

2.3 SITE OPERATIONS

Over the life span of the plant, various processes have been employed including the manufacturing of polyesters, polyurethanes, and specialty plasticizers. PVC was produced at the Hooker/Ruco Site from 1956 until 1975. In 1956, a partnership was formed with Ross & Roberts of Stratford, Connecticut to construct and operate a PVC production facility at the Site. This venture was known as Insular Chemical

Corporation. Insular was later dissolved when Rubber Corporation of America purchased its partner's share. Today, no distinction is made between the property which was under the control of Insular, and the property which was owned by Rubber Corporation of America. The Hooker/Ruco Site encompasses all of this property.

Through the years in which OxyChem operated the facility, various processes were employed including the manufacture of polyesters, polyurethanes, and specialty plasticizers. Other products included vinyl film, vinyl sheeting, solution polyurethanes, polyurethane latexes, and dry blends, and pelletized plastic compounds. A pilot plant produced polyester, plasticizer, and polyurethane products, and the laboratory was utilized for organic chemical synthesis and technical service.

During the 1950s and 1960s, the Hooker/Ruco Site utilized three production wells to provide water to the facility. These three industrial wells correspond to the NYSDEC well numbers 3450, 5368, and 5390. The pumped water was applied in various non-contact facility processes. The total pumpage of these wells ranged from 57 gpm to 324 gpm during the 1950s and ranged from 16 gpm to 140 gpm in the 1960s. The wells were abandoned in 1970. The three wells did not exceed a depth of approximately 150 feet below ground surface (bgs). The wells were shallow by comparison to the Northrop production wells which range in depth from 357 to 570 ft bgs. Recharge basin areas are located at the south end of the Hooker/Ruco Site. Stormwater runoff is directed to the basins, which have also received process water discharge.

2.4 WASTEWATER DISPOSAL PRACTICES

Wastewater from the facility was historically discharged to Sumps 1 through 6. Descriptions of historic wastewater disposal practices to the sumps are provided in the 1992 RI Report. The investigative activities described in the 1992 RI Report showed that additional investigative activities were needed for Sumps 1 and 2. These activities were performed in December 1998 and January 1999, as part of the OU-1 predesign activities. Sump 3 has been remediated by a soil removal action. Sumps 4, 5, and 6 were identified as areas that did not require remediation.

2.5 MUNICIPAL PUMPING CENTERS

The municipal pumping centers for Hicksville, Levittown, Bethpage, and Plainview are located to the northwest, southwest, south and east, respectively, from the Hooker/Ruco Site. Due to the significant amount of industrial pumpage occurring at the Northrop

site, the Plainview municipal pumping center is considered to be beyond the zone of hydraulic influence of the three sites. As a result, only the Hicksville, Levittown, and Bethpage pumping centers were considered in the OU-3 RI Report, and this report. Recently received groundwater results from Nassau County show that large areas of the regional aquifer beyond the zone of hydraulic influence of the three sites is significantly impacted by PCE and TCE. The Nassau County data is presented in Appendix E which shows the areal extent of PCE and TCE presence in the general area of the Site.

Stratigraphic logs for municipal wells for which analytical data were available are included in the OU-3 RI Report for the VCM presence in the vicinity of MW-52.

Available pumpage records from 1970 to 1997 for these municipal wells were compared to the total Northrop pumpage over the same time period. The Northrop pumpage rates were significantly greater than the municipal pumpage rates. For the period from 1979 to 1988, using available municipal pumping rates, the Northrop rates ranged from 1.4 to 2.8 times greater than all the Hicksville, Levittown and Bethpage wells combined.

The natural groundwater flow direction in the Bethpage regional aquifer is from north to south. Pumping of the Northrop production wells would have reinforced (increased) the natural north to south hydraulic gradient from the Hooker/Ruco Site and the northern portions of the Northrop and Navy sites, thereby drawing chemicals from these areas to the Northrop production wells keeping the chemicals on the Northrop and Navy sites. Therefore, the chemicals in groundwater underlying and south of the Hooker/Ruco Site and northern portions of the Northrop and Navy sites would have principally migrated from north to south, thereby preventing extensive lateral migration to the west (toward the Hicksville wells) and to the east from the area of the three sites. This is expected because:

- i) the Hicksville wells are located 1,800 feet upgradient/cross-gradient of the Hooker/Ruco Site;
- ii) the Levittown wells are located 2,800 feet cross-gradient of the natural flowpath from the Hooker/Ruco Site;
- iii) the Northrop wells are located 1,200 feet (GP-14) to 1,500 feet (GP-16) directly downgradient of the Hooker/Ruco Site;
- iv) the pumpage from the Northrop production wells was larger than the pumpage from the Hicksville wells; and
- v) the pumpage of the three former Hooker/Ruco production wells from the 1950s to 1970 would have partially controlled the vertical and horizontal spread of groundwater partially impacted by chemicals from the Hooker/Ruco Site.

2.6 HYDROGEOLOGIC SETTING

The subsurface conditions beneath the area generally consist of a shallow Upper Glacial aquifer and a deeper Magothy aquifer. The Upper Glacial aquifer consists of glacial outwash sand and gravel deposits that range in thickness from approximately 30 feet to 75 feet. The Magothy aquifer consists of a heterogeneous deposit of sand and gravel interbedded with discontinuous lenses of silty to solid clay. The Magothy aquifer is approximately 600 feet to 650 feet in thickness. A 175-foot thick clay deposit underlies the Magothy aquifer and is considered to represent the lower impermeable boundary of the groundwater flow system. Within the Hooker/Ruco Site vicinity, the Magothy aquifer is the primary source of water for municipal and industrial usage.

Groundwater flow in the Upper Glacial and Magothy aquifers in the vicinity of the three sites generally occurs from north to south. The aquifers are sustained primarily by precipitation recharge and by stormwater runoff and industrial water discharge to recharge basins or sumps. Downward vertical gradients from the Upper Glacial aquifer to the Magothy aquifer are predominant over upward vertical gradients. Groundwater flow directions are influenced significantly by the localized effects of municipal and industrial pumping centers and recharge basins.

A detailed description of the regional and Site-specific hydrogeology is provided in Section 4.0 of the OU3 RI Report.

2.7 PREVIOUS INVESTIGATIONS

Several environmental investigations have been conducted at the Hooker/Ruco Site since 1978. Originally, efforts were directed toward understanding past manufacturing processes, waste generation, and waste disposal. A site background report was prepared in July 1981 and presented the Hooker/Ruco Site in the context of its surroundings and examined waste disposal, regional geology and hydrogeology, regional groundwater withdrawals, and groundwater quality.

At that time, the NYSDEC was the lead government agency. A work plan for conducting a soils and groundwater investigation was submitted to the NYSDEC in April 1983. By June 21, 1983, the plan had been approved and the investigation commenced. The investigation consisted of the drilling and installation of six well clusters at locations downgradient of suspected areas of waste disposal, and the drilling

and sampling of two deep test borings in formerly operating sumps. The results of this study were presented in a report entitled "Report of Groundwater & Soils Investigation at the Former Ruco Division Plant Site, Hicksville, New York", dated August 1984.

In July 1987, EPA sent OxyChem a request for information on the Hooker/Ruco Site. A response to the EPA request for information was submitted in September 1988. OxyChem entered into an Administrative Order on Consent with EPA in September 1988. Subsequently, a Field Operations Plan, based on an EPA Work Plan, was submitted for EPA review in October 1988.

Between September 1989 and March 1990, a RI was conducted at the Hooker/Ruco Site. The investigation included a soil-vapor study, electromagnetic terrain conductivity survey, recharge basin (sump) water and sediment sampling, shallow and deep soil sampling and groundwater sampling. A total of 134 soil samples were collected from 50 borings for analysis of target compound list (TCL) parameters and tentatively identified compounds (TICs). Eight deep wells and 14 shallow wells were installed on and off site to complement the existing 12 on-site wells. Two off-site piezometers were installed to help define the groundwater flow pattern. Thirty-nine new and existing wells were sampled and analyzed for TCL/TIC parameters.

The risks for exposure to groundwater at the Hooker/Ruco Site boundary were calculated in the report entitled "Revised Final Risk Assessment and Fate and Transport Report, Operable Unit 1" (RA Report) dated October 1992.

The calculated risks showed that for current residents, the carcinogenic and non-carcinogenic risks were below levels of concern and that for future construction workers (e.g., for remedial action) and trespass children, the risks were within or below the levels of concern (i.e., 10^{-4} to 10^{-6} for carcinogenic risk and Hazard Index <1 for non-carcinogenic risk).

The calculated risks listed in Table 2.1 for future residents show that the majority of the carcinogenic risk (65 to 99 percent) can be attributed to potential exposure to VCM. It is reasonable to assume that if the risk attributable to VCM is controlled, the risks contributed by the other chemicals of concern (e.g., tetrachloroethene (PCE)) would also be controlled.

The risks listed in Table 2.1 were calculated using reasonable maximum exposure (RME) assumptions and the 95% Upper Confidence Limit (UCL) VCM concentration of $68.5 \mu\text{g/L}$. The UCL concentration was calculated using the data base presented in the 1992 RI Report which had a maximum VCM concentration of $560 \mu\text{g/L}$. Groundwater

sampling and analysis performed as part of the Phase I and Phase II Beyond Ruco Property investigations since preparation of the 1992 RI and the RA Report have shown higher concentrations of VCM (up to 6400 µg/L) at well nest MW-52. These results confirm that the potential threat calculated in the RA Report is sufficient to show that a remedial action is necessary for the groundwater because of the VCM presence.

2.8 SUMMARY

Groundwater pumpage rates and periods of pumping throughout the area of the three sites have been highly variable. Also, the locations at which pumping and recharge have occurred have changed with time. These changes have significantly affected local groundwater flow directions and the corresponding groundwater chemical migration pathways. The groundwater pumping for 1970 to 1997 shows that the total pumpage from Northrop production wells (generally in the range of 4,200 to 6,200 gpm except for 1995 (7,411 gpm) and 1997 (3,132 gpm)) for the same time period is significantly greater than the municipal pumpage rates (generally in the range of 1,800 to 4,000 gpm except for 1986 (7176 gpm), 1989 (1,573 gpm) and 1992 (1,590 gpm)). Therefore, it is expected that pumping of the Northrop production wells would have reinforced (increased) the natural north to south hydraulic gradient in the Bethpage regional aquifer, thereby drawing chemicals in groundwater toward Northrop production wells rather than allowing chemical migration to the municipal wells, which are located upgradient or cross-gradient. Thus, extensive lateral migration to the west (toward the Hicksville wells) and to the east from the sites is not expected to have occurred.

This report focuses on remediation of OU-3, which includes chemical loading from the OU-1 groundwater. An evaluation of the mass loadings from the OU-1 groundwater to the OU-3 groundwater was performed to determine the potential effect on the remedial alternatives. The estimates of current mass flux of VCM, PCE, trichloroethene (TCE) and TICs from OU-1 to OU-3 were estimated to be on the order of 0.156, 0.038, 0.053, and 0.301 pounds per day, respectively. It is understood that these fluxes are a measure of the amount of chemicals leaving the Site today and are considerably smaller than the historical chemical fluxes. It is also understood that these current flux values are small compared to the volume of the chemicals known to be present in the off-Site OU-3 area. Consequently, for the purposes of this FS, they are not considered as a separate item during the discussion of remedial alternatives in the following sections. Supporting calculations for these loading estimates are presented in Appendix C. It is also expected that these flux values have been steadily declining over the past years and will continue to decline in the future because untreated process discharges to the on-Site sumps stopped over 22 years ago (i.e., by 1978).

3.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

3.1 INTRODUCTION

This section discusses the remedial action objectives, general response actions, and screening/selection of remedial technologies. Remedial action objectives are developed to provide a focus for the development of response actions and remedial action alternatives. The screening of remedial technologies consists of preliminary and final levels of evaluation, followed by the selection of representative process options.

3.2 REMEDIAL ACTION OBJECTIVES

Remedial action objectives (RAOs) form the basis of the FS and are based on the elevated VCM groundwater presence, the affected environmental media, the pathways of exposure to potential receptors, and cleanup goals or acceptable VCM concentrations. Based on an analysis of these factors, cleanup objectives are determined.

3.2.1 MEDIA OF CONCERN

The Hooker/Ruco Site is a 14 acre site whereas the Northrop/Navy sites were on the order of 500 acres. The focus of this study is on the VCM groundwater subplume, which comprises a small part of the existing regional VOC plume, and is primarily located in the area of well nest MW-52. The primary chemicals in the groundwater in the region of the three sites are VOCs primarily TCE, PCE and VCM. The secondary contaminants are SVOCs and inorganics as follows:

- i) Navy: SVOCs including bis[2-ethylhexyl]phthalate, di-n-butylphthalate, di-n-octylphthalate, 2-methylphenol, 4-methylphenol; 2,4-dimethylphenol, naphthalene, acenaphthylene, fluoranthene, benzo[b]fluoranthene, and pyrene; inorganics including cadmium, chromium, and thallium, and TICs including polyaromatic hydrocarbons [PAHs], substituted benzenes, alkanes, substituted phenols, and carboxylic acids;
- ii) Northrop: inorganics including arsenic, cadmium, and chromium; and
- iii) Hooker/Ruco: TICs including glycols, diols, and acids.

The concentration levels and extent of the regional VOC plume are predominant when compared to the low concentrations and infrequent detections of SVOCs, metals, and TICs. This report focuses on the VCM subplume. The remainder of the regional VOC

plume has been fully addressed by the FS prepared by the Navy and Northrop, However, the impact of the Northrop IRM on each VCM subplume remedial action alternative is also included in this report.

3.2.2 PATHWAYS OF EXPOSURE

The downgradient areas are a major source of drinking water to the Bethpage Water District (BWD). Exposure to human receptors is possible via ingestion, inhalation, or dermal contact with groundwater. However, the particle tracking computer simulations presented in the OU-3 RI showed that the Northrop IRM provides containment for the entire regional groundwater VOC plume, which includes the groundwater underlying the Hooker/Ruco Site and the VCM subplume located in the area of well MW-52. The one exception to this, is that portion of the VOC plume which had migrated south of the Northrop recharge ponds located along the southern boundary of the Northrop site prior to initiation of pumping for the Northrop IRM. In order to protect the public from the chemical presence in this portion of the regional VOC plume, treatment units are currently in place on the impacted municipal wells. Thus, the municipal water users are protected from potential exposure to the regional VOC plume, including the VCM subplume in the MW-52 area. The allowable concentrations of chemicals in drinking water that should not be exceeded to minimize health risks via these exposure routes are discussed in the following section under contaminant-specific application or relevant and appropriate requirements (ARARs) and to be considered (TBC) criteria.

3.2.3 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

The requirements of applicable federal and state statutes were considered in developing preliminary remedial action goals. Tables 3.1 and 3.2 present a summary of federal and New York State ARARs for the VCM in the MW-52 area, respectively. These ARARs may be refined and revised further, if necessary, as the FS proceeds. In developing and selecting remedial alternatives, the degree of public health or environmental protection afforded by each remedy must be considered. Actions that attain or exceed ARARs are given primary consideration.

The definition of ARARs is as follows:

- any standard, requirement, criterion, or limitation under federal environmental law; and

- any promulgated standard, requirement, criterion, or limitation under a state environmental or facility siting law that is more stringent than the associated federal standard, requirement, criterion, or limitation.

Definitions of the two types of ARARs, as well as other TBC criteria, are given below:

- applicable requirements means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that directly and fully address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at the site;
- relevant and appropriate requirements means those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law, while not "applicable", address problems or situations sufficiently similar (relevant) to those encountered at the site, that their use is well suited (appropriate) to the particular site; and
- TBC criteria are non-promulgated, non-enforceable guidelines or criteria that may be useful for developing remedial action, or necessary for determining what is protective to human health and/or the environment. Examples of TBC criteria include EPA Drinking Water Health Advisories, Carcinogenic Potency Factors, and Reference Doses.

ARARs fall into three categories, based on the manner in which they are applied. The characterization of these categories is not exact, as many requirements are combinations of the three types of ARARs. These categories are as follows:

- Chemical Specific: Health-risk-based numerical values or methodologies that establish concentration or discharge limits for particular chemicals. Examples of chemical-specific ARARs include Maximum Contaminant Levels (MCLs) and Clean Water Act (CWA) water quality criteria. In this case the specific chemical is VCM. Chemical-specific ARARs govern the extent of a site cleanup;
- Location Specific: Restrictions based on the concentration of hazardous substances or the conduct of activities in specific locations. These may restrict or preclude certain remedial actions or may apply only to certain portions of a site. Examples of location-specific ARARs include RCRA location requirements and floodplain management requirements. Location-specific ARARs pertain to special site features; and

- Action Specific: Technology- or activity-based controls or restrictions on activities related to management of hazardous substances. Action-specific ARARs pertain to implementing a given remedy.

3.2.3.1 CHEMICAL-SPECIFIC ARARs AND TBCs

This section presents a summary of federal and state chemical-specific ARARs and TBC criteria. All ARARs and TBC criteria provide some medium-specific guidance on "acceptable" or "permissible" concentrations of chemicals.

The Safe Drinking Water Act (SDWA) promulgated National Primary Drinking Water Standard MCLs (40 CFR Part 141). MCLs are enforceable standards for chemicals in public drinking water supply systems. They consider not only health factors but also the economic and technical feasibility of removing a chemical from a water supply system. Secondary MCLs (40 CFR Part 143) are not enforceable but are intended as guidelines for chemicals that may adversely affect the aesthetic quality of drinking water, such as taste, odor, color, and appearance, and may deter public acceptance of drinking water provided by public water systems.

The SDWA also established Maximum Contaminant Level Goals (MCLGs) for several organic and inorganic compounds in drinking water. The NCP (40 CFR Part 300.430(e)(2)(i)) states that MCLGs, if set at levels above zero, shall be attained by remedial actions for groundwaters or surface waters that are current or potential sources of drinking water, where the MCLGs are relevant and appropriate under the circumstances of the release. If an MCLG is found not to be relevant and appropriate, the corresponding MCL shall be achieved where relevant and appropriate to the circumstances of the release. For MCLGs that are set at zero, the MCL promulgated for that chemical under the SDWA shall be attained by the remedial actions. In cases involving multiple chemicals or pathways where attainment of chemical-specific ARARs will result in a cumulative cancer risk in excess of 10^{-4} , criteria in paragraph (e)(2)(i)(A) of Section 300.430 (i.e., risk-based criteria) may be considered when determining the cleanup level to be attained.

Table 3.3 provides Federal SDWA requirements (i.e., MCLs) that may be applicable to remedial actions involving groundwater. Drinking water standards will also be considered as discharge criteria for alternatives which include groundwater treatment.

Reference Dose (RfD), as defined in the EPA Integrated Risk Information System (IRIS), is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily

exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. RfDs are developed for chronic and/or subchronic human exposure to hazardous chemicals and are based on the assumption that thresholds exist for certain toxic effects. The RfD is usually expressed as an acceptable dose (mg) per unit body weight (kg) per unit time (day). The RfD is derived by dividing the no-observed-adverse effect level (NOAEL) or the lowest-observed-adverse effect level (LOAEL) by an uncertainty factor (UF) times a modifying factor (MF). The use of uncertainty factors and modifying factors is discussed in the EPA, Office of Research and Development (ORD) Health Effects Assessment Summary Tables, Fourth Quarter FY 1989 [October 1989-ORD(RD-689)] (USEPA, 1989).

Cancer Slope Factors (CSFs) are used for estimating the lifetime probability (assumed 70-year lifespan) of human receptors contracting cancer as a result of exposure to known or suspected carcinogens. These factors are generally reported in units of kg-day/mg and are derived through an assumed low dosage linear relationship and an extrapolation from high to low dose responses determined from human or animal studies. Cancer risk and CSFs are most commonly estimated through the use of a linearized multistage mathematical extrapolation model applied to animal bioassay results. The value used in reporting the slope factor is the upper 95 percent confidence limit.

EPA Health Advisories are nonenforceable guidelines (TBCs) developed by the EPA Office of Drinking Water for chemicals that may be intermittently encountered in public water supply systems. Health advisories are available for short-term, longer-term, and lifetime exposures for a 10 kg child and/or 70 kg adult. Health advisories may be pertinent for corrective actions involving groundwater, especially for chemicals that are not regulated under the SDWA.

The Clean Air Act (CAA) (42 USC 7401) consists of three programs or requirements that may be ARARs. National Ambient Air Quality Standards (NAAQs) (40 CFR Part 50), National Emissions Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR Part 61), and NSPs (40 CFR Part 60).

EPA requires the attainment and maintenance of primary and secondary NAAQs to protect public health and public welfare, respectively. NAAQs are available for six criteria pollutants (carbon monoxide, lead, nitrogen oxides, ozone, sulfur dioxide, and airborne particulates). These standards are not source specific but rather are national limitations on ambient air quality. The sources of the chemical and the routes of exposure were considered. However, the standards do not consider costs for

achievement or feasibility. States are responsible for assuring compliance with the NAAQs. Requirements in an EPA-approved State Implementation Plan (SIP) for the implementation, maintenance, and enforcement of NAAQs are potential ARARs.

NESHAPs are emission standards for source types (i.e., industrial categories) that emit hazardous air pollutants, and include significant sources of beryllium, vinyl chloride, benzene, asbestos, wet dust particulates, and other hazardous substances.

NSPs are established for new sources of air emissions to ensure that the new stationary sources minimize emissions. These standards are for categories of stationary sources that cause or contribute to air pollution that may endanger public health or welfare. Standards are based upon the best-demonstrated technology (BDT). NSPs may be relevant and appropriate if the pollutant(s) emitted (e.g., from an air stripping tower) and the technology employed during the cleanup action are sufficiently similar to the pollutant and source category regulated by NSPs and are well suited to the circumstances at the site.

The Hooker/Ruco Site is located within the New York City Metropolitan Area which is a non-attainment area for ozone. Therefore, emission of photochemical oxidants (ozone-forming VOCs) are regulated.

New York Ambient Air Quality Standards (6 NYCRR Parts 256 and 257) provides four general classifications of social and economic development and resulting pollution potential upon which standards are based. In addition air quality standards are established to provide protection from adverse health effects of air contamination and to protect and conserve natural resources and the environment. Part 256 provides the air quality classification standards. The Hooker/Ruco Site is likely classified as Level III or Level IV according to Part 256. Part 257 provides natural air quality standards for regulated chemicals, which includes sulfur dioxide, particulates, carbon monoxide, photochemical oxidants, nonmethane hydrocarbons, nitrogen dioxide, fluorides, beryllium, and hydrogen sulfide. Hourly average concentrations of photochemical oxidants and non-methane hydrocarbons are limited to 0.08 ppm and 0.24 ppm, respectively. These are potentially applicable to emissions from groundwater remediation at the site under consideration.

New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700 to 705) regulates reclassification of water based on use and value, including protection and propagation of fish, shellfish and wildlife, recreation in and on the water, public water supplies, and agricultural, industrial and other purposes including navigation. Additionally, the discharge of sewage, industrial waste, or other wastes is regulated so

as not to cause impairment of the best usages of the receiving water as specified by the water classifications at the location of discharge that may be affected by such discharge. Both quantitative standards as well as narrative water quality standards (turbidity, solids, oil, etc.) are provided (see Action-Specific ARARs for Groundwater Effluent Standards, which would be applicable for alternatives including reinjection to the aquifer).

Part 701 provides the classification of surface water and groundwater. Groundwater located south of the Hooker/Ruco Site would be classified as Class GA. The groundwater quality standard (Class GA) for VCM is 2 µg/L.

New York Public Water Supply Regulations (10 NYCRR Part 5) provide requirements for state public water supplies. Table 3.3 provides standards applying to Hooker/Ruco Site compounds. Specific criteria are available (Subpart 5.1.5.2) for VCM. According to these standards, the MCL in public water systems shall be 5 µg/L for a specific list of Principal Organic Contaminants (POCs) or 50 µg/L for other unspecified organic contaminants (UOCs) with a total of 100 µg/L for POCs and UOCs.

3.2.3.2 LOCATION-SPECIFIC ARARs AND TBCs

EPA's Groundwater Protection Strategy (EPA, 1984) policy is to protect groundwater for its highest present or potential beneficial use. This policy will be incorporated into future regulatory amendments. The strategy designates three categories of groundwater:

- Class I - Special Groundwaters: Waters that are highly vulnerable to contamination and are either irreplaceable or ecologically vital sources of drinking water;
- Class II - Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Uses: Waters that are currently used or that are potentially available; and
- Class III - Groundwater Not a Potential Source of Drinking Water and of Limited Beneficial Use. Class III groundwater units are further subdivided into two subclasses.

Subclass IIIA includes groundwater units that are highly to intermediately interconnected to adjacent groundwater units of a higher class and/or surface waters. They may, as a result, be contributing to the degradation of the adjacent waters. They may be managed at a similar level as Class II groundwaters, depending upon the potential for producing adverse effects on the quality of adjacent waters.

Subclass IIIB is restricted to groundwater characterized by a low degree of interconnection to adjacent surface waters or other groundwater units of a higher class within the Classification Review Area. These groundwaters are naturally isolated from sources of drinking waters in such a way that there is little potential for producing adverse effects on quality. They have low resource values outside of mining or waste disposal.

The CAA Prevention of Significant Deterioration (PSD) Standards (40 CFR Part 52.21) require new major stationary sources of air emissions to determine whether they are in NAAQs attainment areas or non-attainment areas. Depending on their status, the sources must meet pertinent PSD requirements (e.g., the lowest achievable emissions rate). These requirements may be relevant and appropriate for remedial actions. The Hooker/Ruco Site and the Northrop and Navy sites are in an NAAQs non-attainment area for ozone.

3.2.3.3 ACTION-SPECIFIC ARARs AND TBCs

RCRA Subtitle C regulates the treatment, storage, and disposal of hazardous waste from its generation until its ultimate disposal. In general, RCRA Subtitle C requirements for the treatment, storage, or disposal of hazardous waste will be applicable if:

- the waste is a listed or characteristic waste under RCRA; and
- the waste was treated, stored, or disposed of (as defined in 40 CFR Part 260.10) after the effective date of the RCRA requirements under consideration.

One or more of the following requirements included in the RCRA Subtitle C regulations may pertain to wastes generated from groundwater treatment at the Hooker/Ruco Site as well as the Northrop and Navy sites:

- hazardous waste generator requirements (40 CFR Part 262);
- transportation requirements (40 CFR Part 263); and
- land disposal restrictions (40 CFR Part 268).

A generator that treats, stores, or disposes of hazardous waste on site must comply with RCRA Standards Applicable to Generators of Hazardous Waste (40 CFR Part 262). These standards include manifest requirements, pre-transport requirements (i.e., packaging, labeling, placarding), record keeping, and reporting hazardous waste.

Standards Applicable to Transporters of Hazardous Waste (40 CFR Part 263) are applicable to off-site transportation of hazardous waste. These regulations include requirements for compliance with the manifest and record keeping systems and requirements for immediate action and cleanup of hazardous waste discharges (spills) during transportation.

RCRA Land Disposal Restrictions (LDR) Requirements (40 CFR Part 268) restrict certain wastes from being placed or disposed on the land unless they meet specific Best Demonstrated Available Technology (BDAT) treatment standards (expressed as concentrations, total or in the Toxicity Characteristic Leaching Procedure (TCLP) extract, or as specified technologies). Removal and treatment of a RCRA hazardous waste or movement of the waste outside of a Corrective Action Management Unit (CAMU), thereby constituting "placement," will trigger the LDR requirements.

Placement of hazardous waste into underground injection wells constitutes "land disposal" under the LDRs. Furthermore, RCRA Section 3020(a) bans hazardous waste disposal by underground injection into or above an underground source of drinking water. RCRA Section 3020(b), however, exempts from the ban all reinjections of treated groundwater into such formations undertaken as part of a CERCLA Section 104 or 106 response action, or a RCRA corrective action, if the following conditions are met:

- the contaminated groundwater is treated to substantially reduce hazardous constituents prior to such injection; and
- the response action or corrective action is sufficient to protect human health and the environment upon completion.

National Environmental Policy Act (NEPA) (42 USC 4321) (40 CFR Part 6) requires Federal agencies to evaluate the environmental impacts associated with major actions that they fund, support, permit, or implement. Specifically, NEPA requires federal agencies to consider five issues during the planning of major actions: (1) the environmental impact of the proposed action; (2) any adverse impacts which cannot be avoided with the proposed implementation; (3) alternatives to the proposed action; (4) the relationship between short-term and long-term effects; and (5) any irreversible and irretrievable commitments of resources which would be involved in a proposed action. All of the listed items are addressed in the detailed evaluation of the FS report.

Control of Air Emissions from Superfund Air Strippers at Superfund Groundwater Sites (OSWER Directive 9355.0-28) is a TBC criterion that guides the control of air emissions

from air strippers at Superfund groundwater remediation sites. For sites located in areas that are not attaining the NAAQs for ozone, add-on emission controls are required for an air stripper with an actual emission rate in excess of 3 pounds per hour or 15 pounds per day, or a potential (i.e., calculated) rate of 10 tons per year of total VOCs. The guideline criteria may be potentially relevant and appropriate for other VOC sources. Generally the guidelines described for air strippers are suitable for VOC air emissions from other vented extraction techniques (e.g., soil vapor extraction) but not from area sources (e.g., soil excavation). Air stripping and/or soil vapor extraction may be included in the remedial activities under consideration at the Hooker/Ruco Site. The Hooker/Ruco Site is located in Nassau County which is a non-attainment area for ozone.

General Pretreatment Regulations for Existing and New Sources of Pollutants (40 CFR Part 403) was promulgated under the CWA and includes provisions for effluent discharge to Publicly Owned Treatment Works (POTW). Discharge of pollutants that pass through or interfere with the POTW, contaminate sludge, or endanger health/safety of POTW workers is prohibited. These regulations should be used in conjunction with local POTW pretreatment program requirements. These regulations are potentially applicable if a groundwater discharge option is the local POTW.

Underground Injection Control Program (40 CFR Parts 144 and 147) regulations were promulgated under the SDWA to ensure that operation of an underground injection will not endanger drinking water sources by violating MCLs or by adversely affecting health. The two types of wells which may apply to remedial activities at the sites are:

- Class I well; injection of wastes (or treated groundwater) beneath the lowermost formation containing an underground drinking water source; and
- Class IV well; injection of wastes (or treated groundwater) into or above an underground drinking water source. Note that injection of untreated groundwater into a Class IV well is banned.

Class IV well standards may be relevant and appropriate for infiltration basins.

New York Environmental Conservation Law (ECL) (New York Consolidated Laws, Chapter 43-B) concerns the conservation, improvement and protection of state natural resources and environment and controls water, land, and air pollution.

The following requirements included in the ECL in particular may pertain to remedial activities at the sites under consideration:

- Article 19 - Air Pollution Control Act provides policy to maintain the quality of the air resources of the state. Regulations for implementing this act are provided in 6 NYCRR Parts 200 to 257;
- Article 27 - New York Solid and Hazardous Waste Management Laws addresses solid and hazardous waste management, including waste transport permits, solid waste management and resource recovery facilities, industrial hazardous waste management, siting of hazardous waste facilities, and inactive hazardous waste disposal sites; and
- Article 70 - Uniform Procedures establishes uniform review procedures for major regulatory programs of the NYSDEC and establishes time periods for NYSDEC action on permits under such programs. Procedures are provided for coordinating permitting for a project requiring one or more NYSDEC permit.

New York Air Pollution Control Requisitions (6 NYCRR Parts 200 to 254) regulates emissions from specific sources. Part 212 General Process Emission Sources provides general requirements. The Hooker/Ruco Site is located in Nassau County which is considered part of the New York City Metropolitan Area according to Part 212.1. The degree of air cleaning required for the different chemical ratings are as follows. For the most stringent rated chemicals (Rating A) emission rate potentials less than 1 lb/hr degree of air cleaning required shall be specified by the state. For Ratings of B, C, or D; for emission rate potentials 3.5 lb/hr or less; the degree of air cleaning required shall be specified by the state (Ratings B or C) or no cleaning is required (Rating D). For emission rate potentials greater than 3.5 lb/hr, reasonably available control technology shall be used. Part 231 regulates new source review for air contamination source projects in non-attainment areas. To be applicable, annual emissions (within a non-attainment area) from the source must exceed the de minimis emission limits. For VOCs the de minimis emission limit is 40 tons per year and for particulates 25 tons per year.

New York State Department of Environmental Conservation (6 NYCRR) Chapter IVB (solid wastes) regulations include hazardous waste generator, transporter, treatment/storage/disposal, and other regulations pertaining to hazardous waste management. One or more other regulations are potentially applicable to wastes generated from groundwater remediation at the sites under consideration.

New York Waste Transport Permit Regulations (6 NYCRR Part 364) governs the collection, transport, and delivery of regulated waste, originating or terminating at a location within the state.

New York General Hazardous Waste Management System Regulations (6 NYCRR Part 370) provides general definitions and sets forth state procedures for making information available to the public, confidentiality, petitioning equivalent testing methods, and petitioning for exclusion of a waste from a particular facility.

New York Identification and Listing of Hazardous Wastes Regulations (6 NYCRR Part 371) establishes procedures for identifying solid wastes subject to regulation as hazardous wastes.

New York Hazardous Waste Manifest System Regulations (6 NYCRR Part 372) establishes standards for hazardous waste generators; transporters; and treatment, storage, or disposal facilities associated with the use of the manifest system and its record keeping requirements.

New York Hazardous Waste Treatment, Storage and Disposal Facility Permitting Requirements (6 NYCRR Subpart 373-1) regulates hazardous waste management facilities located within the state.

New York Final Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (6 NYCRR Subpart 373-2) establishes minimum state standards which define the acceptable management of hazardous waste.

New York Interim Status Standards for Owners and Operators of Hazardous Waste Facilities (6 NYCRR Subpart 373-3) establishes minimum state standards which define the acceptable management of hazardous waste during the period of interim status and until certification of closure.

New York Standards for Managing Specific Hazardous Wastes and Hazardous Waste Management Facilities (6 NYCRR Part 374) contains requirements for generators and transporters of hazardous waste and for owners and operators of facilities managing hazardous wastes.

New York Land Disposal Restrictions Regulations (6 NYCRR Part 376) identifies hazardous wastes that are restricted from land disposal and defines limited circumstances under which an otherwise prohibited waste may be land disposed.

New York Rules on Hazardous Waste Program Fees (6 NYCRR Parts 483 and 484) addresses generator fees; treatment, storage, or disposal facility fees; and waste transporter fees.

New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700 to 705) Parts 700 to 705 provide regulations for the discharge of sewage, industrial waste or other wastes so as not to cause impairment of the best usages of the receiving water as specified by the water classifications at the location of discharge that may be affected by such discharge. Part 703.6 provides Groundwater Effluent Standards. Standards for VCM and other compounds are shown in Table 3.3. Groundwater may be reinjected to the aquifer and would at a minimum, need to comply with Groundwater Effluent Standards. The Hooker/Ruco Site is in Nassau County, so an additional requirement would be a maximum concentration of 1,000 mg/L TDS and 10 mg/L total nitrogen (as N).

New York Technical and Administrative Guidance Memorandum (TAGM) on "Contained-in" Criteria for Environmental Media (TAGM 3028) is a recently available guidance document applicable to soil, sediment, and groundwater contaminated by listed hazardous waste which has been removed from its natural environment. These criteria do not apply to listed or characteristic wastes as initially generated or residuals derived from treating these listed hazardous wastes. This TAGM sets action levels for an environmental medium contaminated by listed hazardous waste which must be met in order to preclude its management as hazardous waste. These criteria are not cleanup levels for contaminated environmental media, but allow these media to be treated as nonhazardous wastes. Therefore, groundwater at the three sites may be treated to meet SPDES standards and discharged on site even if the groundwater is determined to contain listed hazardous constituents. Action levels for VCM in groundwater are presented in Table 3.3.

Two other requirements are listed below which must be met during remedial action but which are not true ARARs. These are not environmental requirements and are not subject to potential ARAR waivers.

Department of Transport (DOT) Rules for Hazardous Materials Transport (49 CFR Parts 107 and 171 to 179) regulate the transport of hazardous materials, including packaging, shipping equipment, and placarding. These rules are considered applicable to wastes shipped off site for laboratory analysis, treatment, or disposal.

OSHA Requirements (29 CFR Parts 1910, 1926, and 1904) regulates occupational safety and healthy requirements applicable to workers engaged in on-site field activities.

3.2.4 REMEDIAL ACTION OBJECTIVES

1. Protect human health from exposure (via ingestion, inhalation, and dermal contact) to VCM, TCE, PCE, and TICs in groundwater at concentrations in excess of New York State MCLs.
2. Restore the aquifer to meet New York State Groundwater Standards and New York State MCLs in a timely manner (30 years). If the aquifer cannot be restored to meet these standards, then, at a minimum, the remedial action objective is to minimize further migration of VCM, TCE, PCE, and TICs to prevent adverse impact on downgradient public and industrial users.
3. Comply with ARARs, unless revised pursuant to an ARAR waiver.
4. Comply with TBCs to the extent practicable.

3.2.5 PRELIMINARY REMEDIAL ACTION GOALS

The preliminary remedial action goals (PRGs) have been selected to be the most stringent of the following three ARARs/TBCs:

- Federal MCLs;
- New York State MCLs; and
- New York State Guidance (TOGs 1.1.1).

The Northrop IRM contains the TVOC regional plume and is expected to require more than 30 years to achieve the above PRGs. This FS presents alternatives, which would enhance the performance of the Northrop IRM by addressing the VCM subplume with a supplemental system. The PRG numerical values are shown in Table 3.3.

3.2.6 AMBIENT AIR QUALITY ARARs

Selected VCM treatment methods must achieve ambient air quality ARARs. The applicable ARAR for VCM is the Air Guide 1 criteria of $0.02 \mu\text{g}/\text{m}^3$. ARARs for TCE and PCE are $0.45 \mu\text{g}/\text{m}^3$ and $1.2 \mu\text{g}/\text{m}^3$, respectively. The toxicity rating for these two parameters is moderate as compared to VCM which has a high toxicity rating.

3.3 GENERAL RESPONSE ACTIONS

This section presents generic outlines of actions that will be considered to address the RAOs for the VCM subplume in the regional groundwater. This section also provides an estimate of the extent of groundwater with elevated VCM presence.

3.3.1 VOLUMES FOR TREATMENT

The delineation of VOC and VCM-impacted groundwater was based on the following sources of groundwater quality information:

- i) groundwater plume maps developed as part of the Remedial Investigation (RI) Report (Geraghty & Miller 1994);
- ii) groundwater quality data collected from early warning outpost wells southeast of the Site;
- iii) Remedial Investigation Report Operable Unit - 3, Hooker Chemical/Ruco Polymers Superfund Site (CRA July, 2000);
- iv) groundwater quality data presented in the RI and Phase 2 RI Reports for the Naval Weapons Industrial Reserve Plant (Halliburton NUS 1992, 1993); and
- v) a NYSDEC letter dated December 5, 1996 and accompanying figure that estimated "the western extent of the groundwater plume emanating from the Northrop Grumman, Navy, and RUCO sites".

Based on these data, the regional VOC plume is approximately 11,300 feet long (north-south axis), by 9,600 feet wide (east-west axis) at its broadest point, by approximately 580 feet at its deepest point. The approximate horizontal extent of VOC-impacted groundwater in Model Layers 1 through 7 was presented previously in the report entitled "Regional Groundwater Feasibility Study", March 1998, and thus are not repeated here.

The horizontal area of groundwater impacted by VOCs was computed for each of Model Layers 1 through 7 (VOCs are not present in Model Layer 8), and the area was multiplied by the model layer thickness to compute the aquifer volume that is impacted. The aquifer volume impacted by VOCs is approximately 33,600,000,000 cubic feet. Multiplying this volume by the aquifer porosity of 30 percent yields the volume of water (in cubic feet) impacted by VOCs, and multiplying this value by 7.48 gallons per cubic foot yields the volume of water, in gallons, impacted by VOCs. Therefore, the quantity

of groundwater contained within the impacted portion of the aquifer is approximately 75 billion gallons. The Navy/Northrop FS addresses this overall plume.

The area of groundwater impacted by VCM was similarly determined (i.e., same model layers, same porosity assumptions, etc.). The aquifer volume impacted by the VCM subplume is estimated to be 2,000 feet long (at its longest point), by 1,350 feet wide (at its widest point), by 430 feet deep, which equates to approximately 1.25 billion gallons.

Typically, the removal of 10 or more pore volumes is needed to restore an aquifer to MCLs. Using a factor of 10, this is equal to 750 billion gallons of groundwater for the overall regional plume, and 12.5 billion gallons for the VCM subplume. The VCM subplume volume represents approximately 1.7 percent of the regional VOC plume.

Northrop terminated pumping from nearby wells GP-11, GP-13 and GP-16 in 1998. This has eliminated the external forces that have been causing the VCM subplume to migrate in an easterly direction. Thus, it is now expected that the VCM subplume will cease being pulled laterally from its preferred natural north-south pathway. With time, the VCM subplume would not be expected to grow any wider as it continues its pathway toward GP-1. The VCM subplume is shown in plan view on Figure 3.1 and in cross-section on Figure 3.2. The area of VCM presence shown on Figures 3.1 and 3.2 was determined based on analytical results from groundwater samples collected in April and May of 1996.

3.3.2 GENERAL RESPONSE ACTIONS

This generic outline of actions provides the framework for specific technologies and process options that must be considered in order to meet the remedial action objectives for the groundwater with elevated VCM concentrations. The following are the general response actions that are being considered for the VCM subplume in the MW-52 area:

- No Further Action - Northrop IRM (No VCM treatment);
- Enhanced Northrop IRM (Supplemental VCM treatment at IRM wells if necessary);
- VCM Subplume Containment, Treatment, and Discharge for VCM Mass Reduction;
- VCM Subplume Containment, Treatment, and Discharge to Achieve Groundwater ARARs; and
- In Situ Treatment of the VCM Subplume by Biosparging /Chemical Oxidation/Enhanced Bioremediation.

3.4 IDENTIFICATION AND SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS

3.4.1 INITIAL SCREENING OF TECHNOLOGIES/PROCESS OPTIONS

Preliminary screening of numerous technologies and process options for each of the above-noted response actions has previously been conducted. The RGFS examined various technologies and process options and thus, need not be repeated in this FS. A summary of the technologies and process options examined in the RGFS is summarized in Table 3.4. Numerous reports/memos have been prepared which allow for direct advancement to a more detailed screening of the response actions (i.e., the treatment methods have already previously been evaluated). The alternative response action components are summarized below in Section 3.4.2. Any remedial action that is selected to address the VCM subplume will also address the TCE, PCE, and other groundwater contaminants commingled within the VCM subplume.

3.4.2 SUMMARY OF INITIAL SCREENING OF TECHNOLOGIES/PROCESS OPTIONS

The following technologies/process options combine to form the remedial alternatives:

| <i>General Response Action</i> | <i>Technology</i> | <i>Process Option</i> |
|--------------------------------|---------------------------------------|---|
| No Further Action | Northrop IRM | Northrop IRM |
| Enhanced IRM | Northrop IRM | Northrop IRM with Supplemental VCM Treatment |
| Removal | Extraction | Extraction Wells |
| Disposal | Beneficial Reuse Surface Discharge | Process Water/Potable Water Reinjection |
| Treatment | Physical | Filtration/Volatilization/ Catalytic Oxidation |
| In Situ Treatment | Biological | Bioremediation/ Enhanced Bioremediation Biosparging |
| | Chemical | Chemical Oxidation |

3.4.3 EVALUATION CRITERIA FOR DETAILED SCREENING OF TECHNOLOGIES

The remedial technologies and process options presented above are discussed in more detail based on the criteria of effectiveness, implementability and cost. A brief description of each of the following criteria follows:

- Effectiveness
 - Protection of human health and environment, reduction in toxicity, mobility, and volume; and permanence of solution.
 - Ability of the technology to address the estimated areas or volumes of contaminated medium.
 - Ability of the technology to meet the remediation goals identified in the remedial action objectives.
 - Technical reliability (innovative versus well-proven) with respect to chemicals and site conditions.
- Implementability
 - Overall technical feasibility at the site.
 - Availability of vendors, mobile units, storage and disposal services, etc.
 - Administrative feasibility.
 - Special long-term maintenance and operation requirements.
- Cost (Qualitative)
 - Capital cost.
 - Operation and maintenance (O&M) costs.

All of the items listed above may not apply directly to each technology and, therefore, will be addressed only as appropriate. Evaluations at this stage generally focus on effectiveness and implementability, with less emphasis on cost evaluations. At this stage, none of the technologies will be eliminated based on cost. Each technology presented in this section is not necessarily intended to be implemented alone, as it may be combined with other technologies into remedial action alternatives.

For each technology, one representative process will be selected to more effectively develop and evaluate alternatives without limiting flexibility during remedial design. The specific process actually used to implement the remedial action at a site may be selected during the remedial design phase or in the bid evaluation/selection of the

remedial action contractor, and may differ from the selected representative process option.

**3.4.4 DETAILED SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS**

**3.4.4.1 NO FURTHER ACTION - NORTHROP IRM
(NO VCM TREATMENT)**

This scenario is considered to provide a baseline level to which other remedial technologies and alternatives can be compared. This option includes the fact that the Northrop IRM is already operating. This scenario consists of continued operation of the Northrop IRM system (expected to be required for more than 30 years) and would include VCM removal if and when the VCM groundwater subplume reaches the IRM extraction system, however treatment for VCM is not included. Treatment for VOCs at the existing impacted municipal wells would continue as is currently the case.

Effectiveness. The no further action scenario would be effective in capturing the VCM subplume, however no active treatment would be provided until the VCM reaches the Northrop IRM System. Thus VCM concentration reductions enroute would be limited to those provided by naturally occurring processes. Treatment would remain in place on all impacted wells to protect users.

The absence of a treatment method for VCM at the Northrop IRM limits public and environment protectiveness. Long-term periodic groundwater monitoring would be required to assess the ability of the aquifer to naturally lower VCM concentrations through natural attenuative processes. Because groundwater with elevated VCM presence would remain on site, 5-year site reviews would be conducted to evaluate the VCM subplume conditions.

Implementability. There are currently no operating considerations associated with the no action scenario as the Northrop IRM is already operating.

Cost. Capital costs would be zero. The reliance of this alternative on the Northrop IRM for the treatment of groundwater from the VCM subplume will result in a minor contribution by OxyChem toward the Northrop IRM cost of \$56,000,000. However, the amount of this contribution is indeterminate at this time.

Conclusion. This scenario is implementable, however it may not be effective if the VCM reaches the Northrop IRM system at concentrations above that system's currently designed capability to address the VCM without supplemental treatment to treat the air discharge.

**3.4.4.2 ENHANCED NORTHROP IRM/
SUPPLEMENTAL VCM TREATMENT (IF NECESSARY)**

The enhanced Northrop IRM scenario consists of continued operation of the Northrop IRM system with the addition of the performance of VCM sentry monitoring. If this monitoring shows that VCM is migrating to aquifer regions within the hydraulic influence of the IRM groundwater extraction system at concentrations which would require supplemental treatment to prevent Air Guide 1 exceedances, the IRM treatment system would be modified to address the VCM presence.

Effectiveness. The enhanced Northrop IRM scenario achieves the remediation objectives, however the required time frame is longer than for the other 'action' alternatives. Continued migration of the VCM subplume downgradient of the MW-52 area would not be prevented and thus the toxicity, mobility, and mass of VCM would not be reduced, other than that offered by natural attenuation, until the VCM reaches the Northrop IRM system. Sentry monitoring for VCM would be required to ensure that the treatment for VCM at the Northrop IRM wells was in place before the VCM reaches the wells. The sentry monitoring and subsequent supplemental VCM treatment at the Northrop IRM system would prevent VCM Air Guide 1 excursions, thereby protecting the Northrop IRM workers and local residents. The Northrop IRM will prevent VCM from the MW-52 area from migrating to the BWD wells thereby protecting the BWD water supply.

Implementability. This scenario is easily implemented. In fact, the Northrop IRM is already operating and sentry wells are already installed and being monitored by Northrop (i.e., well nest GM-23). Treatment technologies for elevated levels of VCM in groundwater are readily available. Implementation of this scenario would require long term groundwater monitoring. Additional O&M would be required for the supplemental VCM treatment components if determined to be needed. The treatment plant may require a revised permit for off-gases.

Cost. Capital costs would be moderate and O&M costs would be low.

Conclusion. The scenario is effective and implementable.

3.4.4.3 GROUNDWATER REMOVAL

Extraction Wells

The extraction option uses a pumping well system, comprised of a series of wells completed in the overburden deposits, which can be used to capture groundwater with elevated VCM presence for treatment. The wells used in the capture system would be designed and located to provide optimum efficiency in capturing the target groundwater while minimizing the collection of clean groundwater.

Effectiveness. The effectiveness of an extraction well system depends largely on the extent of chemical presence and the geology and hydrogeology. Pumping tests previously performed and the geology/hydrogeology confirm a high yield aquifer in the portions of the aquifer where VCM is present, and because the VCM presence extends to depths of several hundred feet bgs, extraction wells should effectively control the migration of the VCM and remove the affected groundwater for subsequent treatment. The use of wells to extract groundwater will reduce VCM mass and should attain the remediation goals identified in the remedial objectives over the long term. The technology is reliable and minimal effects on human health and the environment would be expected during implementation.

Implementability. Groundwater extraction through a pumping well system can be readily implemented. The technology uses readily available equipment and techniques and has been widely used in similar situations, including the Northrop IRM to address the regional VOC plume. Implementation of this technology would require long term operation and maintenance. Maintenance may require periodic replacement of mechanical components and well flushing to remove fine-grained material that may clog the wells. Local and state permits will be required for installation of the extraction wells. Implementation could be negatively affected by difficulties associated with purchasing land or obtaining access/easements for extraction well locations. Northrop has been selling large pieces of formerly used industrial land. These transactions have decreased the amount of land available for the installation and operation of wells and/or forcemains.

Cost. Both capital and O&M costs are moderate.

Conclusion. The extraction well system is effective and implementable.

3.4.4.4 GROUNDWATER TREATMENT

In this section, treatment technologies for the removal of VCM from extracted groundwater will be discussed. Discussion of treatment technologies that may be required for water conditioning before or after primary treatment, such as filtration or sedimentation for the removal of suspended solids, will also be included as part of the discussions. It is noted that although VCM is the primary compound being addressed, other VOC compounds are present. There may also be other sorts of compounds that are present that require treatment prior to discharge of the treated groundwater. None the less, this evaluation will continue to focus on treatment for VCM as it is the primary parameter of concern and is expected to drive the treatment selection.

Carbon Adsorption

Activated carbon adsorption is a frequently applied technology for the removal of elevated levels of VOCs from groundwater. The fundamental principle behind activated carbon treatment involves the physical attraction of organic solute molecules to exchange sites on the internal pore surface areas of the specially treated (activated) carbon grains. As groundwater is filtered through the adsorbent, the organic molecules eventually occupy all of the surface sites on the carbon grains. The exhausted carbon must then be either regenerated or disposed of according to federal (RCRA) or New York State regulations. Activated carbon will adsorb many organic compounds to some extent but is most effective for the less polar and less soluble compounds. VCM adsorbs very poorly on activated carbon.

Effectiveness: Carbon adsorption is a well proven, reliable technology that would be effective for removing most of the VOCs from the groundwater with the exception of VCM which adsorbs poorly on activated carbon. Spent carbon containing the concentrated organic chemicals would have to be regenerated or disposed of in a hazardous waste landfill.

Implementability. Carbon adsorption would be readily implementable if it was an appropriate technology. There are a sufficient number of vendors that provide carbon adsorption units. General construction permits and a TSD permit will likely be required for the implementation of carbon adsorption technologies.

Cost. Capital costs are low while O&M costs range from low to high, depending on the carbon usage rate, which is a function of influent chemical concentration.

Conclusion. Carbon adsorption is a viable technology for treating VOCs in the groundwater, however, it is not effective for VCM removal and thus is not relevant for further consideration.

Volatilization

Volatilization or air stripping technology is well suited for the removal of VOCs including VCM from extracted groundwater. This aeration process encourages the transfer of VOCs found in groundwater from the aqueous phase to the gas phase as defined by Henry's Law. In general, air stripping is used for VOCs with a Henry's Law constant greater than or equal to 3.0 atm-L/mole (Camp, Dresser and McKee Incorporated, 1985). Removal efficiencies of VOCs typically exceed 99 percent depending on the operating parameters as well as the physical properties of the VOCs. VCM is one of the easier volatiles to air strip.

The countercurrent packed tower is the most commonly used air stripping configuration. Water is distributed over the top of the unit while air is forced upward through the bottom. Loosely fitted packing material serves to increase the air/water interface area to provide maximum mass transfer. Key factors that influence process performance include air to water ratio, height of packing, type of packing material, operating temperature, surface hydraulic loading, and contact time.

Steam stripping uses steam to strip VOCs from groundwater. This technology is very similar to air stripping, except that steam is used as a carrier gas and provides heat to enhance removal. Steam stripping is generally considered for product recovery and/or for removal of organic compounds that are only slightly more volatile than water. For VCM and the other VOCs present in the groundwater, steam would not typically be required.

Effectiveness. Air stripping is a well proven and reliable technology that would be effective for removing VCM and the other VOCs from groundwater. Removal efficiencies greater than 99 percent can theoretically be achieved for the contaminants present. Since air stripping only removes the VOCs from the water and concentrates them in the off-gas, the off-gas will require treatment by means such as granular activated carbon adsorption, catalytic oxidation, or thermal destruction. The need and type of off-gas treatment depends on the specific chemicals and their concentration. As previously mentioned, granular activated carbon does not effectively treat VCM. Thus catalytic or thermal treatment are the most likely process options for treatment of the VCM off-gas.

Steam stripping does not provide any advantage in effectiveness beyond that of air stripping.

Implementability. Air stripping would be readily implementable. There are a significant number of vendors that provide air stripping technology. In order to meet New York State Ambient Air Quality Standards, control of off-gas emissions will be required, as well as an air permit. Construction permits and a TSD permit will also likely be required.

A maintenance problem associated with air stripping is the channeling of flow resulting from clogging in the packing material. Common causes of clogging include high oils, suspended solids, and iron concentrations, and slightly soluble salts such as calcium carbonate. None of these nuisance constituents are expected to be present at elevated concentrations, which would present a problem for treatment of the VCM subplume.

Cost. The capital costs are moderate and O&M costs range from low to moderate. The presence of VCM requires off-gas treatment by processes such as catalytic oxidation, thus increasing capital and O&M costs.

Conclusion. Air stripping, via a countercurrent packed tower, is an effective and reliable technology for removing VCM and the other VOCs from the groundwater. Catalytic and thermal destruction are the most likely process options for the off-gas treatment (at the present time).

Filtration

Filtration is a process using a porous medium to remove suspended solids from a liquid. It is valuable in groundwater treatment as a pre-treatment to remove suspended solids before other treatment processes and/or for the final cleaning or polishing of treated effluent. It is effective in removing organic and inorganic chemicals (particularly metals) that are bound to suspended solids in groundwater, often reducing the need for further treatment of these chemicals.

Liquid filtration may be accomplished by numerous methods including screens, fibrous fabrics (paper or cloth), ultrafiltration, or beds of granular material. Flow through a filter can be encouraged by pressure on the inlet side or by drawing a vacuum on the filter outlet.

Effectiveness. This technology is widely used for the removal of suspended materials. Filtering systems can be staged to progressively remove smaller materials; many system variations have been designed to reduce clogging and provide easy maintenance.

Filtration is especially useful in reducing concentrations of particulate metals and organic compounds that are bound to suspended solid materials. These compounds may not be easily removed by other treatment methods such as aeration or carbon adsorption, making filtration a common pre-treatment step for these technologies. Suspended solids in groundwater from the VCM subplume are not a concern.

Implementability. Filtration systems are commercially available from a wide variety of manufacturers and can be readily ordered to almost any specification. No permits, other than general construction permits would likely be required for the implementation of filtration technologies.

Filter media would occasionally have to be replaced or regenerated, potentially resulting in the generation of sludges requiring specialized disposal because of chemical content.

Cost. Capital costs for filtration are low, as are O&M costs. Although not anticipated in this situation, O&M costs may elevate slightly if frequent turbidity in the pumped groundwater requires additional filter maintenance or increases sludge volumes requiring disposal.

Conclusion. Filtration may be required as a process option for groundwater treatment followed by a precipitation process when needed for particulate metals removal. However, the requirement of inorganics treatment must be evaluated further during remediation and is not considered further in this FS.

3.4.4.5 GROUNDWATER DISCHARGE TECHNOLOGIES

Extracted groundwater must eventually be discharged following treatment. The available discharge options include beneficial reuse as potable or process water or recharge to the aquifer. The large volumes of treated water make other potential options (i.e., off-Site discharge via hauling or forcemains) cost prohibitive and are not discussed further in this FS.

Beneficial Reuse

Beneficial reuse includes the use of the treated water as potable water and/or process water. After reuse, the water would either be discharged to the sanitary sewer system or to subsurface discharge, depending on the condition of the water after use. Subsurface discharge would be performed as described below.

Effectiveness. Beneficial reuse of the treated groundwater is a means of reducing the demand on the area groundwater resources and is a requirement of the area.

Implementability: The groundwater would be required to be treated to Class GA (i.e., potable water) standards in order to be useable for most purposes. The reuse of the water would be based on the chemical concentrations achieved by treatment. Additionally, beneficial reuse is not easily implementable as a distribution system (e.g., forcemains) would need to be constructed.

Cost: The cost to implement beneficial reuse is moderate. A use for the water would need to be identified and a distribution system constructed.

Conclusion: Beneficial reuse is retained for further consideration because it is required in this area, reduces the demand on a limited resource and is of moderate cost.

Subsurface Discharge

Subsurface discharge includes the use of injection wells, spray irrigation, or infiltration basins to return treated groundwater into the aquifer. Underground injection wells can be coupled with extraction wells to create a closed system in which pumping and injection rates balance one another, and serve as a dynamic containment system for controlling plume migration. Spray irrigation and infiltration basins use gravity-aided discharge into the aquifer.

Effectiveness. Subsurface discharge is an effective means of disposing of the volume of water generated by a groundwater pumping/treatment system. Injection wells offer the advantage of decreasing groundwater remediation time by increasing the groundwater flow rate through the aquifer.

Implementability. Recharge basins are readily implementable. Space is available and basins are easily constructed and are widely used in the surrounding area. Subsurface discharge would require that groundwater be treated to either action or background levels prior to reinjection. Subsurface discharge of water typically require a State

Pollution Discharge Elimination System (SPDES) permit. The permit sets limitations on chemical concentrations, and possibly flow rates, of disposed water. Installation of an injection well system for underground injection is implementable, however, achieving a closed system may be difficult, considering the complexity of pumping/recharge basins within the area of concern. Injection wells can also be maintenance intensive. Spray irrigation requires large areas of unused, uncontaminated land which is not readily available in such a densely industrialized urban area.

Cost. The capital and O&M costs for recharge basin(s) are low.

Conclusion. Recharge basins are appropriate for use in developing remedial alternatives. Because the costs for reinjection are high compared to use of the recharge basins and because implementation of reinjection is questionable due to complex aquifer use patterns, reinjection is eliminated from further consideration. Spray irrigation is eliminated because of the nonavailability of appropriate land area.

3.4.4.6 IN SITU TREATMENT

Chemical Oxidation

Chemical oxidation can destroy an extensive variety of organic constituents in groundwater, sediment, and soil. In situ chemical oxidation is an innovative technology based on the delivery of a suitable oxidizing agent to impacted groundwater in order to destroy or detoxify the chemical constituents by converting them to innocuous and harmless compounds. There is a variety of oxidants available, and laboratory studies suggest that treatment time may be significantly reduced relative to other technologies. In situ chemical oxidation can be used to significantly reduce the VCM concentrations in the vicinity of MW-52. Application of the oxidizer is anticipated to occur at intervals of at least one month. The treatment would greatly reduce the biological communities in the area of oxidant injection. Oxidation will take place in a period of hours after which the oxidizer will be depleted. Once the oxidants are depleted, the area treated by the oxidants will gradually begin to infill with chemicals and microbial populations from the surrounding unoxidized areas as the groundwater continues to flow and mix along its southerly migration route. Various chemical oxidation processes for treating organic compounds in groundwater are evaluated below with respect to their ability for treatment of the chemicals in the VCM subplume.

i) Air and Pure Oxygen

Gases such as air and pure oxygen are weaker in terms of chemical reactivity as compared to liquid oxidants. Air and pure oxygen are capable of oxidizing VCM, however they are not as effective as liquids because the contact time required for the chemical reaction necessary to reduce the VCM concentrations is much greater. None the less, oxidation will occur if extended contact time is available and thus air and pure oxygen are retained as possible oxidizing agents for the remediation of the VCM subplume.

ii) Ozone

Ozone is a gas capable of oxidizing a wide range of organic and inorganic compounds. It is commonly used to destroy a variety of organic constituents, however, it requires certain precautions because it is an extremely reactive gas. It cannot be shipped or stored, and must be generated on site immediately prior to its application. Ozone rapidly decomposes to oxygen in aqueous solutions containing impurities such as particulates or organic matter. The effectiveness of ozone treatment in destroying many organic compounds is significantly enhanced in the presence of ultraviolet radiation and acidic pH. However, very little published data are available on the effectiveness and cost of in situ ozone treatment, particularly for chlorinated volatile compounds in groundwater. Due to these difficulties, the use of ozone as an oxidizing agent for the remediation of the VCM subplume is eliminated.

iii) Hydrogen Peroxide/Fenton's Reagent

Hydrogen peroxide is an acidic, moderate strength oxidizing agent. It is commercially available in aqueous solutions over a wide range of concentrations. Hydrogen peroxide is used frequently in industrial wastewater treatment to detoxify cyanide, sulfide, and a variety of organic compounds. However, it can result in the formation of toxic intermediate products such as epoxy derivatives. In the presence of catalysts, particularly ferrous ions, hydrogen peroxide is decomposed to hydroxyl and perhydroxyl radicals. These free radicals are very powerful oxidants which react with a wide variety of organic compounds and are the basis of what is known as "Fenton's Reagent". Although the most common field applications thus far have been based on Fenton's Reagent, the process has several disadvantages. For example, the reaction of hydrogen peroxide with high concentrations of some organic and inorganic compounds can be strongly exothermic (heat producing) and can result in possible explosion due to gas evolution. The instability of hydrogen peroxide is also another problem. In addition, effective treatment with hydrogen peroxide or Fenton's Reagent usually

requires low pH and use of corrosive reagents such as sulfuric acid. Because hydrogen peroxide/Fenton's Reagent produce exothermic reactions and hydrogen peroxide is unstable, use of these as oxidizing agents for the remediation of the VCM subplume were eliminated.

iv) Potassium Permanganate

Potassium permanganate is a strong oxidizing agent that reacts readily with many organic compounds, including chlorinated solvents such as TCE, DCE and VCM. The half-lives of these compounds range between less than a minute to four hours under lab conditions. Reaction of permanganate with these chemicals results in the formation of carbon dioxide, water, potassium chloride, and manganese oxide. The effectiveness of permanganate oxidation of chlorinated solvents has been demonstrated in laboratory and pilot-scale level tests (Base Borden Permanganate Test¹, Portsmouth DOE Plant Permanganate Test²). Potassium permanganate is a stable reagent, commercially available and easy to handle in both solid and aqueous form.

Based on the above discussions, potassium permanganate is selected as the most appropriate oxidizing agent for the VCM subplume. The following paragraphs on effectiveness, implementability and cost are all discussed with respect to potassium permanganate.

Effectiveness: In situ chemical oxidation has been demonstrated to be successful at other sites, and is effective against a wide range of chlorinated and non-chlorinated compounds in a variety of soil types. In situ chemical oxidation would offer a reliable and cost-effective remedial alternative for the VCM subplume. In situ chemical oxidation can significantly reduce the elevated VCM concentrations and may provide conditions suitable for biodegradation to occur or potentially be even more effective in the areas downgradient of the chemical oxidation zones (the reduction in toxic levels of VCM combined with residual oxygen presence may provide enhanced conditions for biodegradation to occur).

¹ Schnarr, M. J., Truax, C. T., Farquhar, G. J., Hood, E. D., Gonullu, T., and Stickney, B. (1998). "Laboratory and controlled field experiments using potassium permanganate to remediate trichloroethylene and perchloroethylene DNAPLs in porous media". *Journal of Contaminant Hydrology*, 29:205-224.

² Jerome, K. M., Riha, B., and Looney, B. B., 1997. Final Report for Demonstration of In Situ Oxidation of DNAPL using the Geo-Cleanse® Technology Westinghouse Savannah River Company, WSRC-TR-97-0028.

Due to the slow rate of movement of the VCM subplume, the introduction of potassium permanganate can be done on a periodic basis rather than as a continuous injection stream.

Implementability: An in situ chemical oxidation system can be readily implemented. Permanganate solution can be applied through either horizontal injection wells or vertical injection wells. This treatment scenario would be implemented after conducting appropriate laboratory studies to determine injection and consumption rates. The need to inject on a periodic basis (i.e., monthly, bimonthly, quarterly) makes this alternative fairly easy to implement. Implementation of this treatment scenario would require long-term groundwater monitoring. Groundwater samples would be analyzed for chloride and VCM to evaluate the treatment process. Permission to inject potassium permanganate into the aquifer would require State approval. The State has expressed concern over potassium permanganate due to the presence of trace concentrations of metals in the potassium permanganate and a general reluctance to allow any foreign substance to be injected into the aquifer. Tests have been prepared by GSHI to address these concerns under another phase of the Hooker/Ruco Site remediation.

Cost: The capital costs are moderate and O&M costs range from low to moderate, depending on the volume of permanganate used and duration of treatment.

Conclusion: The use of chemical oxidation may be technically implementable at a relatively low cost, compared to other treatment alternatives, such as pump and treat subject to the requirements/costs of the delivery/mixing systems needed and time/quantity of oxidant needed. The duration of treatment is comparable to pump and treat alternatives, because the treatment method relies on the southerly migration of the VCM subplume to facilitate the destruction of the VCM [i.e., the northern limit of the elevated VCM subplume concentration has to migrate south past the delivery system location(s)]. The duration of treatment can be decreased through the use of multiple injection points throughout the VCM subplume. A benefit of in situ treatment as compared to pump and treat methods is that groundwater is not extracted or discharged from/to the aquifer. This would ensure less stress to the environment. Additionally, construction of recharge basins and forcemains would not be required. Prevention of groundwater use and routine monitoring for assessing VCM migration makes this approach a viable remedial option. The technology should be retained for further consideration.

Enhanced Bioremediation

A review of the data presented in the OU-1 Predesign Investigation report indicated that some natural attenuation of PCE and VCM by biodegradation is occurring in the vicinity of monitoring wells MW-50J1, MW-50J2, MW-52S and MW-52I. The evaluation of PCE and VCM biodegradation resulted in the following key observations:

- i) the distribution of redox parameters indicates an area of reducing conditions (methanogenic) in the groundwater in the vicinity of monitoring wells MW-50J1, MW-50J2, and MW-52S;
- ii) PCE degradation products (TCE and 1,2-DCE) were observed in monitoring wells in association with the parent compound PCE, indicating that degradation of PCE is occurring in localized areas;
- iii) The high ratio of cis-1,2-DCE relative to 1,1-DCE and trans-1,2-DCE indicates that the presence of cis-1,2-DCE is the result of biodegradation reactions;
- iv) VCM degradation products (ethane and ethene) were observed at monitoring wells MW-50J1, MW-50J2, MW-52S and MW-52I, indicating that biodegradation of VCM by reductive dehalogenation is occurring; and
- v) Aerobic conditions, which are highly conducive to the oxidation of VCM, exist in the vicinity of MW-52I and downgradient of the Hooker/Ruco Site at GM-10I.

The redox data indicate that conditions in the groundwater in the southern portion of and immediately downgradient of the Hooker/Ruco Site are predominantly reducing. Decreases in PCE and VCM concentrations combined with the presence of daughter products and redox indicators of the appropriate redox potential provides strong evidence that PCE and VCM are undergoing biodegradation. Biodegradation of PCE to TCE and 1,2-DCE is indicated at monitoring wells in the methanogenic groundwater at MW-50J1, MW-50J2 and MW-52S. The predominance of 1,2-DCE relative to 1,1-DCE indicates that the 1,2-DCE present in the groundwater is a biodegradation product of PCE degradation. The presence of ethene and ethane in the groundwater indicates that anaerobic biodegradation of VCM also is occurring in the groundwater.

The results of this preliminary natural attenuation evaluation indicate that destructive natural attenuation processes have contributed to the reductions in PCE and VCM concentrations over time, which result in the biotransformation of PCE and VCM to relatively innocuous compounds (i.e., ethene, ethane, methane, chloride, carbon dioxide and water). Thus bioremediation is a viable treatment alternative for VCM and other VOCs.

Enhanced Aerobic Biodegradation

It may be necessary or beneficial to enhance the degradation of VCM by performing enhanced aerobic degradation. Enhanced aerobic degradation would involve the optimization of the nutrient and oxygen concentrations in groundwater. This can be achieved by:

1. Injection of inorganic sources of nitrogen and phosphorous along with a low level (few PPM) of a suitable carbon source (e.g., methanol, methane, propane etc.), to optimize the growth of indigenous aerobic microbial population; and
2. Maintaining adequate level of dissolved oxygen in groundwater via air sparging/or the use of intercepting socks containing oxygen release compounds.

The requirement for nitrogen, phosphorous and carbon sources would be determined during the Phase I VCM subplume remediation (discussed in Section 4.2.4). The following paragraphs on effectiveness, implementability and cost are all discussed with respect to the general principle of enhanced aerobic degradation

Effectiveness: In situ enhanced aerobic degradation is effective against a wide range of lower chlorinated and non-chlorinated volatile compounds in a variety of soil and groundwater environments. In situ enhanced aerobic degradation would offer a reliable and cost-effective remedial alternative for the chemicals in the VCM subplume and those from the OU-1 groundwater. In situ enhanced aerobic degradation can enhance the biodegradation of these chemicals.

The downgradient edge of the VCM subplume in the regional aquifer has moved a distance of approximately 1,600 feet in the intermediate zone (100 to 180 feet bgs) to approximately 2,300 feet in the deep (180 to 220 feet bgs) and very deep (>270 feet bgs) zones, in a time period of 45+ years. This is equal to a migration rate ranging from 36 to 51 feet/yr. For the purposes of this report, a value of 60 feet/yr will be used. The use of a higher rate of migration will provide a conservative evaluation of how quickly (faster) and how much additive is needed to address the VCM subplume. Because of this slow rate of migration, it is possible to introduce nitrogen/phosphorous/carbon, if needed, on a periodic basis rather than as a continuous injection stream. The method of introduction will be determined during the design phase.

Implementability: An in situ enhanced aerobic degradation system can be readily implemented. The nitrogen/phosphorous/carbon can be applied, if needed, through

the same delivery system as used for oxygen (either horizontal or vertical injection wells). This treatment scenario would be implemented after conducting appropriate laboratory studies. The need to inject on a periodic basis (i.e., monthly, bimonthly, quarterly) makes this alternative fairly easy to implement. Implementation of this treatment scenario would require long-term groundwater monitoring. Groundwater samples would be analyzed for chloride, nutrients (i.e., phosphate, nitrate), TOC, oxygen, carbon dioxide, and VCM to evaluate the treatment process.

Cost: The capital costs are moderate and O&M costs are low due to the expected low volume of nitrogen/phosphorous/carbon required for the treatment.

Conclusion: Similar to chemical oxidation the use of aerobic degradation may be technically implementable at a relatively low cost, compared to other treatment alternatives, such as pump and treat. The duration of treatment is comparable to pump and treat alternatives, because the treatment method relies on the southerly migration of the VCM subplume to facilitate the destruction of the VCM (i.e., the northern limit of the elevated VCM subplume concentration has to migrate south past the delivery system location). The duration can be decreased through the use of multiple injection points throughout the VCM subplume. A benefit of in situ treatment as compared to pump and treat methods is that groundwater is not extracted or discharged from/to the aquifer. This would ensure less stress to the environment. Additionally, construction of recharge basins and forcemains would not be required. Prevention of groundwater use and routine monitoring for assessing VCM migration makes this approach a viable remedial option. The technology should be retained for further consideration.

Enhanced Anaerobic Degradation

It may be necessary or beneficial to enhance the degradation of VCM by performing enhanced anaerobic degradation. Enhanced anaerobic degradation would involve the optimization of the nutrient and carbon source concentrations in groundwater. This can be achieved either by:

1. Injection of inorganic sources of nitrogen and phosphorous along with a higher level (up to 0.1 percent) of a suitable carbon source (e.g., molasses, yeast extract, lactate, HRC etc.), to optimize the growth of indigenous anaerobic microbial population; or
2. the use of intercepting socks containing hydrogen release compound (HRC).

The requirement for nitrogen, phosphorous and carbon sources would be determined during the Phase I VCM subplume remediation (discussed in Section 4.2.4). The

following paragraphs on effectiveness, implementability and cost are all discussed with respect to the general principle of enhanced anaerobic degradation.

Effectiveness: In situ enhanced anaerobic degradation is effective against a wide range of higher chlorinated volatile compounds in a variety of soil and groundwater environments. The onset of reductive dechlorination of VCM may be somewhat slower than that for more chlorinated VOCs because more reducing conditions are required. Once appropriate conditions are established, the rates are an order of magnitude slower than an aerobic process. The degradation half-lives for anaerobic degradation are measured in weeks to months. In situ enhanced anaerobic degradation may offer a reliable and cost-effective remedial alternative for the VCM subplume if reduced conditions can be adequately enhanced.

Due to the slow rate of movement of the VCM subplume the introduction of nitrogen/phosphorous/carbon can be performed, if needed on a periodic basis rather than as a continuous injection stream.

Implementability: An in situ enhanced anaerobic degradation system can be implemented. The system will degrade PCE and TCE readily, however, it may be difficult to maintain the highly reductive conditions needed to insure the effective anaerobic degradation of cis-DCE and particularly VCM, given the current, tending to oxidic, plume conditions.

The nitrogen/phosphorous/carbon can be applied, if needed, through either horizontal injection wells or vertical injection wells. This treatment scenario would be implemented after conducting appropriate laboratory studies. The need to inject on a periodic basis (i.e., monthly, bimonthly, quarterly) makes this alternative fairly easy to implement. Implementation of this treatment scenario would require long-term groundwater monitoring. Groundwater samples would be analyzed for chloride, nutrients (i.e., nitrate and phosphate), TOC, redox sensitive parameters (i.e., redox potential, dissolved oxygen, sulfate, and dissolved iron), ethene, and VCM to evaluate the treatment process.

Cost: The capital costs are moderate and O&M costs are low due to the expected low volume of nitrogen/phosphorous/carbon required for the treatment.

Conclusion: The use of anaerobic degradation may be technically implementable at a relatively low cost, compared to other treatment alternatives, such as pump and treat. The duration of treatment is comparable to pump and treat alternatives, because the treatment method relies on the southerly migration of the VCM subplume to facilitate

the destruction of the VCM (i.e., the northern limit of the elevated VCM subplume concentration has to migrate south past the delivery system location). The duration can be decreased through the use of multiple injection points throughout the VCM subplume. A benefit of in situ treatment as compared to pump and treat methods is that groundwater is not extracted or discharged from/to the aquifer. This would ensure less stress to the environment. Additionally, construction of recharge basins and forcemains would not be required. Prevention of groundwater use and routine monitoring for assessing VCM migration makes this approach a viable remedial option. However, due to the fact that VCM is more easily oxidized under aerobic conditions than reduced under anaerobic conditions, the use of anaerobic degradation technology will not be retained for further consideration.

Biosparging

The results of the laboratory groundwater treatability study and the predesign field activities showed that conditions exist in the plume that are likely to be conducive to aerobic degradation. These results confirm that it is possible to consider the use of biosparging technologies in an in situ application to enhance the VCM degradation. The process would involve the injection of air into the groundwater formation. The rate of injection would be regulated to provide sufficient oxygen to increase the dissolved oxygen content of the aquifer to 10-12 mg/L. That injection rate would maximize the oxygen available to enhance aerobic degradation in the aquifer and it would minimize the removal of VCM from the groundwater by transport to the vadose zone where it is released from the water column. Any VCM released would be in such low concentrations that biological activity in the vadose zone should be sufficient to complete the reduction of the VCM to innocuous components.

It is likely that pure oxygen could significantly enhance the effectiveness of the biosparging process and therefore its use in place of air will be considered. The use of biosparging is likely to be a viable technology. The following paragraphs on effectiveness, implementability and cost are all discussed with respect to the general concept of biosparging.

Effectiveness: In situ biosparging is effective in treatment of a wide range of chlorinated and non-chlorinated volatile compounds in a variety of soil types. In situ biosparging would offer a reliable and cost-effective remedial alternative for the chemicals in the VCM subplume. In situ biosparging can significantly reduce the chemical concentrations.

Due to the slow rate of movement of the VCM subplume, the introduction of air or pure oxygen to the aquifer can be done on a periodic basis rather than as a continuous injection process.

Implementability: An in situ biosparging system can be readily implemented. Air injection can be applied through horizontal injection wells or vertical injection wells. This treatment scenario would be implemented after conducting appropriate laboratory studies to assess iron and manganese precipitation and potential clogging. The need to inject on only a periodic basis (i.e., monthly, bimonthly, quarterly) makes this alternate fairly easy to implement. Implementation of this treatment scenario would require long-term groundwater monitoring. Groundwater samples would be analyzed for chloride, oxygen, carbon dioxide, and VCM to evaluate the treatment process.

Cost: The capital costs are moderate and O&M costs range from low to moderate, depending on the volume of air required and the duration of treatment.

Conclusion: The use of biosparging is implementable at a relatively low cost, compared to other treatment alternatives, such as pump and treat. The duration of treatment is comparable to pump and treat alternatives, because the treatment method relies on the southerly migration of the VCM subplume to facilitate the destruction of the VCM (i.e., the northern limit of the elevated VCM subplume concentration has to migrate south past the delivery system location). The duration of treatment can be decreased through the use of multiple injection points throughout the VCM subplume. A benefit of in situ treatment as compared to pump and treat methods is that groundwater is not extracted or discharged from/to the aquifer. This would ensure less stress to the environment. Additionally, the construction of recharge basins and forcemains would not be required. Prevention of groundwater use and routine monitoring for assessing VCM migration makes this approach a viable remedial option. The technology should be retained for further consideration.

3.4.4.7 IN SITU DELIVERY SYSTEM

Each of the in situ technologies discussed in Section 3.4.4.6 require a system to deliver the nutrients/additives to the VCM subplume. This section presents two process options: vertical injection wells and horizontal injection wells.

Vertical Injection Wells

Under this process option, vertical wells would be installed to serve as injection locations for whichever in situ process is selected. The following paragraphs on effectiveness, implementability and cost are all discussed with respect to a vertical injection system.

Effectiveness: The injection wells would be effective in delivering the required materials to the formation, since the wells would be designed and spaced for maximum distribution. While injection wells are effective, studies have shown that in some cases, particularly when the screened interval is lengthy, vertical wells sometimes have difficulty in distributing the additives evenly across the entire screened interval. In general, the injected materials may preferentially exit the well in the upper section of the well screen with the injected volume decreasing with distance from the top of the screen. Proper design of the injection well can ensure that the injected materials are spread more uniformly throughout the vertical profile of the impacted groundwater. Design considerations include modifying the screen slot size, the screen length, or the use of packers to segregate the screen interval, etc. Additionally, vertical injection wells can also be readily utilized as monitoring wells if desired.

Implementability: Vertical groundwater injection wells could be easily installed to the depth of the VCM plume (200 to 400 feet below ground) using common drilling techniques. Additives (air, potassium permanganate, nutrients, etc.) could be forced into the formation using either static head within the well or using pump supplied pressure.

Cost: The capital and O&M costs for vertical injection wells are relatively low in comparison with horizontal wells.

Conclusion: Vertical injection wells are retained for further consideration.

Horizontal Injection Wells

Under this process option, horizontal wells would be installed in a west-east direction across the VCM subplume to serve as an injection trench/gallery for whichever in situ process is selected. The following paragraphs on effectiveness, implemetability and costs are all discussed with respect to a horizontal delivery system.

Effectiveness: Horizontal wells screened across the VCM subplume would be effective in distributing the required materials laterally within the aquifer. However, due to the

high ratio of horizontal to vertical hydraulic conductivity (100:1 for the Magothy Aquifer, 10:1 for the Lloyd Aquifer) it is possible that vertical distribution throughout the aquifer could be somewhat impeded. The long screen lengths of horizontal injection wells results in similar distribution concerns as experienced for vertical wells, however, these concerns can also be addressed through technological design input.

Implementability: Horizontal wells in the oil industry have been installed to depths on the order of 20,000 feet. In the case of environmental projects, many horizontal wells have been installed to depths of 100 to 300 feet. Given the depth that has been reached for the oil industry, the installation of horizontal wells on the order of 400 feet bgs for the VCM subplume should not pose a problem.

Costs: The capital and O&M costs for horizontal injection wells are moderate to high.

Conclusion: Horizontal injection wells are retained for further consideration.

Summary: Although both vertical and horizontal injection wells would be effective in delivering the nutrients/additives to the VCM subplume, further discussion of injection wells in this document will be limited to the use of vertical injection wells. Vertical wells are easier to install and work with and therefore are used in the alternatives evaluation in the following sections of this report. In reality, a decision to utilize vertical or horizontal injection wells would be made during the design stage.

3.4.4.8 SUMMARY OF FINAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS - GROUNDWATER

The evaluations of technologies and process options, based on effectiveness, implementability, and cost, are summarized in Table 3.5. In this table, the technologies are organized according to the general response actions developed in Section 2.3.

3.4.4.9 SELECTION OF REPRESENTATIVE PROCESS OPTIONS

The technologies and selected representative process options to be further considered in this report are as follows:

- No Further Action - Northrop IRM;
- Enhanced Northrop IRM;
- Extraction wells;

- Treatment Technologies:
 - Air stripping, with catalytic oxidation off-gas treatment, and
 - In situ Chemical Oxidation and/or Enhanced Bioremediation and/or Biosparging; and
- Discharge:
 - Beneficial reuse as process/potable water, and
 - Subsurface discharge.

4.0 DEVELOPMENT AND DESCRIPTION OF REMEDIAL ACTION ALTERNATIVES

The primary regional environmental concern, as delineated in previous investigations [Geraghty & Miller, Inc. Remedial Investigation (RI) Report (1994); the U.S. Navy RI Reports (Haliburton, NUS 1992 and 1993); and the OxyChem/Ruco RI Reports (Leggette, Brashears, & Graham, Inc. 1990); and CRA, 1999], is the presence of VOCs in groundwater, primarily TCE, PCE, and VCM. PCE and TCE have a broad distribution and have been detected in groundwater beneath and downgradient of all three sites. A subplume of VCM has been detected in the northwestern portion of the VOC plume in the vicinity of MW-52. The development, description, and evaluation of remedial action alternatives to address the VCM subplume are described in the following sections of this FS.

In the RI report prepared for Northrop (Geraghty & Miller, Inc. 1994), remedial action objectives were identified for groundwater. Those objectives included; elimination of exposure pathways on and off site by preventing the off-site migration of groundwater with elevated chemical presence; monitoring potential off-site receptors and providing groundwater treatment, as necessary, to eliminate exposure; and coordinate the Northrop, Navy and Hooker/Ruco remedial actions to prevent the spread of groundwater with elevated chemical concentrations and/or the duplication of efforts.

Based on these objectives, and meetings with the NYSDEC, Nassau County Department of Health (NCDOH), BWD, Navy, OxyChem, and Ruco, Northrop proposed and implemented a full-scale on-site groundwater containment and treatment remedy as an IRM (Northrop IRM) prior to completion of the RGFS. The IRM is designed to prevent further migration of groundwater with elevated chemical presence off the three sites, by enhancing the hydraulic containment/barrier which already exists due to current groundwater pumping and recharge operations at the Northrop and Navy facilities. In addition to the maintained pumping of existing on-site well GP-1, new on-site extraction wells and a treatment system were installed. The IRM is described in greater detail in Section 4.2.2.

This report is intended to examine alternatives which would enhance the Northrop IRM by addressing the VCM subplume before it reaches the IRM groundwater extraction wells.

4.1 RATIONALE FOR DEVELOPMENT OF ALTERNATIVES

Remedial action alternatives have been assembled based on the potential for these alternatives to meet the RAOs described in Section 3.2.4 of this report. In Section 3, general response actions and the related remedial technologies were identified and discussed to determine the remedial technologies and process options that are most suited to VCM treatment. This section presents the remedial alternatives, selected to address the VCM subplume within the VOC plume. The alternatives also address other VOCs (PCE, TCE, and TICs) within the subplume. All alternatives comply with the Site RAOs, and the requirements of the NCP.

The remedial alternatives are identified below. Concurrence from EPA was received on December 1, 1998 as to which alternatives would be compared in this FS.

- Alternative 1: No Further Action - Northrop IRM (No VCM Treatment);
- Alternative 2: Enhanced Northrop IRM (Supplemental VCM Treatment if Necessary);
- Alternative 3A: VCM Subplume Containment, Treatment, and Discharge to Achieve VCM Mass Reduction;
- Alternative 3B: VCM Subplume Containment, Treatment, and Discharge to Achieve Groundwater ARARs;
- Alternative 4A: In Situ Treatment of VCM Subplume by Enhanced Aerobic Bioremediation;
- Alternative 4B: In Situ Treatment of VCM Subplume by Chemical Oxidation; and
- Alternative 4C: In Situ Treatment of VCM Subplume by Biosparging.

The alternatives have been developed to address the VCM subplume located within the regional VOC groundwater plume. Currently, VCM impacted groundwater has been detected in the northwestern portion of the VOC plume, and does not appear to have migrated south of Northrop production well GP-5.

4.2 DESCRIPTION OF ALTERNATIVES

Descriptions of each of the remedial alternatives are presented in this section and include general unit process descriptions. The details provided in this section are intended to facilitate the evaluations and comparative analyses performed in Section 5.0. Actual dimensions, quantities, and equipment types will be identified and selected

during the remedial design. The seven potentially applicable alternatives identified in Section 4.1 are described in the sections that follow.

4.2.1 **ALTERNATIVE 1: NO FURTHER ACTION - NORTHROP IRM (NO VCM TREATMENT)**

Alternative 1 includes the continued operation of the Northrop IRM. This includes pumping and treatment (where applicable) of existing Northrop production well GP-1 and the three recently installed extraction wells (Wells ONCT-1, ONCT-2, and ONCT-3), as well as on-site monitoring to address the entire VOC plume. This scenario currently meets the RAOs for the area by providing mass removal from the aquifer through groundwater extraction and treatment, and prevents the regional VOC groundwater plume (including the VCM subplume) from migrating from the Hooker/Ruco, Northrop, and Navy properties (see Figure 3.1). Natural attenuation would be used to address VOCs not captured by the extraction wells. Treatment on the downgradient public water supply wells has also been provided by Northrop. Treatment for VCM is not included as part of the Northrop IRM. It is possible that the VCM may never get to the Northrop IRM at concentrations above MCLs and therefore treatment may never be required. Northrop is currently monitoring for VCM at sentinel wells, located upstream of their extraction wells, to insure that adequate notice of advancing VCM is provided.

The IRM includes pumping and treating 1,075 gpm from GP-1 and a total of 2,300 gpm from the three recently installed extraction wells located along the southern boundary of the Northrop facility. The well locations are shown on Figure 4.1. The extracted groundwater is conveyed via underground piping to one of two treatment facilities. One treatment facility is for extraction well GP-1 and the other for extraction wells ONCT-1 through ONCT-3.

The GP-1 treatment facility consists of an air stripper with a 12 inch diameter by 20-foot tall stack for removing VOCs from the groundwater via a 5600 cubic feet per minute (cfm) blower. Treated water from GP-1 is discharged to Plant Building 5 recharge basins. The ONCT treatment facility consists of a 24-inch diameter by 70-foot tall air stripping tower for removing VOCs from the groundwater, and off-gas treatment for the air stripper discharge. Treated water flows by gravity to a 46,000-gallon clearwell where it is either pumped into the existing Northrop distribution system or flows (by gravity) to the existing storm sewer line that discharges to existing aeration basins and then to the south recharge basins. In either scenario, groundwater is eventually discharged to the south recharge basins for disposal. By recharging the treated water into the south and Plant 5 recharge basins, a hydraulic barrier to contaminated groundwater is formed

throughout the upper portions of the aquifer. When combined with pumpage from the on-site production wells and extraction wells screened in the lower portion of the aquifer, the hydraulic barrier on the Northrop property is complete.

Off-gas from both systems is collected and treated via vapor phase granular activated carbon (VPGAC) beds. VOCs from the air stream (off gas) are adsorbed by the VPGAC beds prior to discharge to the atmosphere. The VPGAC system is regenerated on-site using steam, which is available at the Northrop facility. During VPGAC carbon regeneration, the steam heats the carbon, releasing adsorbed compounds, and carrying the compounds out with the waste steam. The regeneration steam is then condensed, forming a liquid phase which is separated from the water and then collected in drums and disposed of off site. The separated water is reinjected into the inlet water line of the air stripper for treatment.

Alternative 1 anticipates that natural attenuation will be a significant factor in reducing the concentrations of chemicals from the Hooker/Ruco Site in the VCM subplume, but it is likely to be slow and may not be completely effective. The Northrop IRM is a pump and treat system specifically designed to treat TCE and PCE, therefore any TCE and PCE from the Hooker/Ruco Site that is not degraded by the microbial population present in the aquifer will be treated when it reaches the Northrop IRM. The Northrop IRM is capable of treating VCM in the groundwater however the off-gas treatment system may be inadequate to effectively treat the air stripper air discharges. The IRM would not treat the TICs, but the TICs consist of organic acids, ketones, and ethers that are readily biodegradable and are expected to be utilized by the indigenous microbial population in the aquifer. It is very unlikely that the TICs could reach the Northrop IRM without being degraded. The data from the predesign investigation show that TICs are not present at MW-52. This suggests that they may have already been degraded upgradient of MW-52 and will therefore never influence the IRM treatment system.

Alternative 1 relies on the Northrop IRM which is expected to operate for greater than 50 years. The Northrop RGFS shows that after 30 years of pumping and treating, the TCE concentration in GP-1 is still on the order of 170 µg/L. This is significantly above the MCL of 5 µg/L. Based on observations at other pumping and treatment remedial actions, the general trend is for groundwater concentrations to initially decrease relatively rapidly and then continue to decrease more slowly with time. Thus, it is not unreasonable to expect that the IRM may need to pump for at least an additional 20 years (50 total) to achieve the MCL. Thus, the operating period is considered very long. For consistency, the operating periods of the remedial action alternatives in this FS will be classified using the following descriptions:

| Operating Period (Years) | $x \leq 3$ | $3 < x < 10$ | $10 = x < 30$ | $30 = x < 50$ | $x \geq 50$ |
|-----------------------------|------------|--------------|---------------|---------------|-------------|
| Descriptor | very short | short | medium | long | very long |

Computer simulations performed by Northrop and OxyChem show that for Alternative 1, VCM may migrate from the area of MW-52 to GP-1 at concentrations which require future supplemental treatment. This alternative does not provide for potential supplemental VCM treatment.

4.2.2 **ALTERNATIVE 2: ENHANCED NORTHROP IRM (SUPPLEMENTAL VCM TREATMENT IF NECESSARY)**

Alternative 2 includes the continued operation of the Northrop IRM. This includes pumping and treatment (where applicable) of existing Northrop production well GP-1 and the three recently installed extraction wells (Wells ONCT-1, ONCT-2, and ONCT-3) as well as on-site monitoring to address the entire VOC plume. In addition, monitoring is included to determine when or if future supplemental treatment for VCM is necessary. This scenario meets the RAOs for the area by providing mass removal from the aquifer through groundwater extraction and treatment, and prevents the groundwater plumes from migrating from the Hooker/Ruco, Northrop, and Navy properties (see Figure 3.1). Natural attenuation and treatment at the downgradient public water supply wells would be used to address VOCs not captured by the extraction wells, if any.

The groundwater extraction, treatment and discharge methods for the Northrop IRM are described in Section 4.2.1.

Hydrogeologic modeling of the Bethpage regional aquifer was conducted by OxyChem to evaluate the extent of VCM migration from the MW-52 area under the influence of the Northrop IRM. The details of the hydrogeologic modeling conducted by OxyChem are presented in Appendix A. The migration of VCM was simulated under the steady-state groundwater flow conditions associated with the Northrop IRM. The VCM migration simulation shows that for Alternative 2, VCM may migrate from the area of MW-52 to GP-1 at concentrations which require further supplemental treatment (see Figure A.3.5 of Appendix A). Thus, Alternative 2 includes sentry monitoring for VCM at the 16 locations shown on Figure 4.2. Monitoring is proposed to be performed at ten existing wells [MW-52 S, I; and D, MW-53I, D1 and D2; GM-12I; and GM-23S, I, and D; and the two new well nests MW-58 and MW-59. (These wells are discussed in

Section 4.2.3.)). Well nest MW-52 is the well with the highest VCM concentration and was selected to observe the trend in VCM concentrations. Well nest MW-53, at which VCM has not been detected, was selected to monitor the groundwater west of the VCM presence. Wells GM-12I, GM-23S, GM-23I, GM-23D, MW-58, and MW-59 were selected to observe if VCM is migrating southward at concentrations which may require supplemental VCM treatment at GP-1. Northrop well nest GM-72 is already installed in the same area as that for proposed well nest MW-59. The installation of VCM sentry wells downgradient of GP-2 is not necessary at this time because VCM from the area of well MW-52 has not yet migrated to GP-2. The need to install VCM sentry wells downgradient of GP-2 would be re-evaluated if VCM is detected in GP-2 at concentrations above the MCL value of 2 µg/L.

The monitoring frequency would be semi-annual. Semi-annual monitoring is sufficient because of the relatively slow rate of VCM migration and would provide adequate lead time for the design and installation of supplemental VCM treatment, if needed, at well GP-1. Annual sampling and analysis would then be performed thereafter for a period of 3 years to observe trends. The wells to be monitored and the monitoring frequency after the 3-year period would be based on observed trends.

Well nests MW-52, GM-23, and GM-72 are being monitored by Northrop as part of the Northrop IRM hydraulic and groundwater quality monitoring plan. It is believed that a data and cost sharing arrangement for the monitoring of these wells should be arranged between OxyChem and Northrop to prevent duplicative activities.

In addition to the described monitoring, an ongoing plume tracking program would be implemented to monitor the advance of the VCM subplume toward the Northrop IRM. If deemed necessary, the advance of the VCM subplume will be compared to the modelled results using the groundwater model developed for the regional TVOC plume. The plume tracking efforts will be used to insure that the Northrop IRM effectively captures the VCM subplume in its entirety.

TCE, PCE, VCM, and TICs present in the VCM subplume would be addressed by the Northrop IRM as described for Alternative 1 in Section 4.2.1. Because VCM is not effectively treated, the Northrop IRM is affected by this alternative which may require the addition of a VCM treatment component for the air stripper off-gas.

Alternative 2 relies on the Northrop IRM which is expected to operate for greater than 50 years. Thus, the operating period is considered very long.

4.2.3 ALTERNATIVES 3A AND 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE

Alternatives 3A and 3B both involve pumping groundwater from three extraction wells located within the VCM subplume. Alternative 3A consists of pumping and treating groundwater for VCM for approximately 5 years so that supplemental VCM treatment is not required at the Northrop IRM. Alternative 3B consists of pumping and treating groundwater for VCM for approximately 30 years to achieve the groundwater MCL for VCM. Alternatives 3A and 3B are discussed in detail in Sections 4.2.3.1 and 4.2.3.2, respectively.

4.2.3.1 ALTERNATIVE 3A: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE FOR VCM MASS REDUCTION

Alternative 3A involves pumping from the vicinity of MW-52 to remove sufficient VCM mass from the present area of elevated VCM presence (northwest portion of VOC plume) so that VCM from the MW-52 area will not migrate to the Northrop IRM wells at concentrations which would require separate supplemental treatment in the future. The hydrogeologic modeling efforts that have been performed show that irrespective of whether GP-2, GP-5, or extraction wells installed in the MW-52 area are pumped, the VCM component of the VOC plume is within the capture zone of the Northrop IRM (Alternative 1 and 2). Consequently, it is expected that all of the VCM will eventually reach and be captured by the Northrop IRM wells which are an active component of this alternative for the VCM subplume.

The Air Guide 1 criteria for VCM is $0.02 \mu\text{g}/\text{m}^3$. The VCM groundwater concentration needed to exceed this criteria for a flow rate of 1,100 gpm at GP-1 is calculated to be $8.3 \mu\text{g}/\text{L}$. This alternative would implement an MW-52 area groundwater extraction system to remove sufficient VCM mass from the MW-52 area such that VCM concentrations in groundwater extracted from GP-1 remain below $5 \mu\text{g}/\text{L}$ in order to provide sufficient confidence that the VCM air concentrations at GP-1 would not exceed the Air Guide 1 criteria of $0.02 \mu\text{g}/\text{m}^3$.

The MW-52 area system extraction well layout simulated to determine the effect of removing a portion of the VCM mass from the MW-52 area on the VCM concentrations at GP-1 was a multiple well system consisting of one well (subplume purge well SPPW-1) located approximately 500 feet downgradient of MW-52 (where current VCM concentrations $>1,000 \mu\text{g}/\text{L}$) with two additional wells (SPPW-2 and SPPW-3) located approximately 1,000 feet downgradient of MW-52 (where current VCM concentrations

range between 10 and 100 $\mu\text{g/L}$). The proposed extraction well locations are shown on Figure 4.3 and a schematic cross-section is shown on Figure 4.4. Figure 4.4 shows that the elevated VCM presence is located in depth intervals ranging from approximately 100 to 360 feet bgs.

The extraction well locations were selected to ensure that the lateral extent of the cross-gradient VCM presence in the MW-52 area (i.e., east-west dimension) would be hydraulically contained by the MW-52 area system. The proposed well locations are near the area of the highest VCM concentrations (based on the current information), and are appropriate for VCM mass removal. In order to verify that the extraction wells are within the area of highest VCM concentrations and are appropriate for VCM mass removal, the delineation of the VCM subplume will be refined during the Remedial Design. The majority of the VCM with concentrations greater than 100 $\mu\text{g/L}$ in this aquifer interval will be captured by the MW-52 area wells as shown on the particle tracking figures in Appendix A. These locations also would reduce the mass of other chemicals that would be drawn to the MW-52 area wells, and require treatment at the MW-52 area system treatment facility from the Northrop and Navy sites (e.g., TCE = 12000 $\mu\text{g/L}$ at well HN-24I). The depth and locations of SPPW-2 and SPPW-3 were selected to extract VCM which is downgradient of the zone of capture of SPPW-1 to provide assurance that GP-1 will not require supplemental VCM treatment in the future because of the VCM from the MW-52 area. Pumping SPPW-2 and SPPW-3 at a low rate was selected rather than increasing the pumping rate of the upgradient well. Increasing the pumping rate of the upgradient well would expand the east-west width of the capture zone which could draw groundwater with elevated TCE/PCE concentrations from the Northrop and Navy sites (e.g., from the area of HN-24I). This is not desirable as it would spread the TCE/PCE further west and increase the cost of treatment for the MW-52 area system.

Particle tracking simulations were conducted for Alternative 3A to evaluate the extent of hydraulic containment achieved by the MW-52 area system. The results of the particle tracking simulations are presented in Section 3.3 of Appendix A. Particles were released around the limit of the estimated VCM subplume in the shallow (<100 feet bgs), intermediate (100 to 180 feet BGS), deep (180 to 270 feet bgs), and very deep (>270 feet bgs) aquifer depth intervals. The advective migration of these particles was simulated under the steady-state groundwater flow conditions associated with the MW-52 area system and the Northrop IRM. The particle tracking simulations demonstrate that the VCM Subplume Containment system provides hydraulic containment of the shallow, intermediate, and deep VCM impacted groundwater. The complete hydraulic containment of the VCM impact in the very deep zone is not achieved by the MW-52 area system. Some particles released around the perimeter of the very deep VCM

impact migrated beyond the MW-52 area system and were captured by GP-1. As described above, the purpose of the MW-52 area system for Alternative 3A is to provide VCM mass removal, not to provide complete containment of the VCM.

VCM migration simulations were conducted for Alternative 3A to evaluate the duration of pumping from the VCM Subplume Containment system that would be necessary to prevent the occurrence of VCM concentrations at GP-1 that exceed 8.3 µg/L. The results of the VCM migration simulations are presented in Section 3.3 of Appendix A. Two VCM migration simulations were conducted. The first VCM migration simulation was conducted under the influence of pumping both the MW-52 area system and Northrop IRM for a duration of 7.5 years, after which time the VCM migration simulation was continued to the end of 80 years under the influence of the Northrop IRM pumping only. The second VCM migration simulation was conducted under the influence of pumping both the MW-52 area system and Northrop IRM for a duration of 5 years, after which time the VCM migration simulation was continued to the end of 80 years under the influence of the Northrop IRM pumping only. For the 7.5-year MW-52 area system pumping duration, the simulated VCM concentration at GP-1 remains below a concentration of 5 µg/L (i.e. 4.7 µg/L). For the 5-year MW-52 area system pumping duration, the simulated VCM concentration at GP-1 marginally exceeds a concentration of 5 µg/L (i.e. 5.2 µg/L). Thus, operating the MW-52 area system for five years achieves the concentration objectives at GP-1.

The area of VCM presence shown on Figures 3.1 and 3.2 was determined based on analytical results from groundwater samples collected in April and May 1996. It is likely that the VCM has migrated further to the south since that time. Thus, as part of Alternative 3A two new well nests consisting of a shallow, intermediate, and deep well at each nest (i.e., MW-58 and MW-59) would be installed at the locations shown on Figure 4.5 to confirm the southerly extent of VCM presence. This information would be used to ensure that the MW-52 area extraction wells are properly located. The wells would be sampled after they were installed, so that the appropriate intervals to be screened by the individual monitoring wells in each well nest can be determined.

VCM sentry monitoring is proposed to be performed at ten existing wells (MW-52S, I, and D; MW-53I; D1 and D2; GM-12I; and GM-23S, I, and D; (see Figure 4.2) and the two new well nests (MW-58 and MW-59). Well nest MW-52 is the well with the highest VCM concentration and was selected to observe the trend in VCM concentrations. Well nest MW-53, at which VCM has not been detected, was selected to monitor the groundwater west of the VCM presence. Wells GM-12I, GM-23S, GM-23I, GM-23D, MW-58, and MW-59 were selected to observe if VCM is migrating southward beyond the VCM source control wells at concentrations which may require supplemental VCM

treatment at GP-1. The monitoring frequency will be the same as that described in Section 4.2.2 for Alternative 2 (semi-annual).

Construction of the treatment plant and recharge basin in the vicinity of the SPPW extraction wells is preferable, however, space and access requirements may require that the facilities be built at the Hooker/Ruco Site. Thus, the costs have been estimated with the assumption that the Hooker/Ruco Site location will be utilized. It is proposed to locate the treatment facility for the MW-52 area system in the southwest corner of the Hooker/Ruco Site, and discharge the treated water to either an on-site recharge basin to be constructed in the northwest portion of the Site (see Figure 4.6) or to an existing recharge basin.

Alternative 3A discussed herein describes a pumping alternative consisting of the installation of extraction wells in the vicinity of MW-52, to be operated in conjunction with the Northrop IRM, to address the VCM subplume. Two other pumping scenarios, identified as using existing extraction wells "GP-2" and "GP-5", were also evaluated, but for the reasons identified below were eliminated in favor of the MW-52 area system. Both the GP-2 and GP-5 scenarios consisted of continued operation of the Northrop IRM with additional pumping from GP-2 or GP-5 to address the VCM subplume.

Neither the GP-2 nor GP-5 scenario is required for hydraulic control of the VCM subplume. Computer modeling performed shows that the Northrop IRM (ONCT-1, ONCT-2, OWCT-3 and GP-1) contains all of the regional VOC plume and thus controls the VCM subplume. Therefore, similar to the MW-52 area system, the only purpose of pumping GP-2 or GP-5 would be to prevent the further southerly migration of VCM from the area of MW-52.

Computer modeling and costing was performed for three pumping scenarios; one for GP-2, (700 gpm), and two for GP-5 (700 gpm and 975 gpm). Particle tracking was performed to determine the effect that varying pumping rates at GP-2 (i.e. in the range from 500 to 1,000 gpm) would have on the western extent of capture. The simulation results show that pumping GP-2 at 700 gpm best prevents the further migration of VCM, reinforces the western extent of capture and prevents supplemental VCM treatment from being required at GP-1.

The estimated present worth costs (capital and O&M costs) for the three pumping scenarios, and the MW-52 area system are summarized below:

Pumping Scenario

Estimated Present Worth Cost

| | |
|-----------------|----------------------------|
| GP-2 (700 gpm) | \$5,680,000 |
| GP-5 (700 gpm) | \$13,140,000 |
| GP-5 (975 gpm) | \$15,710,000 |
| MW-52 (600 gpm) | \$5,912,000 to \$6,119,000 |

The GP-5 (700 gpm) scenario has lower costs than the GP-5 (975 gpm) scenario because of the lesser water volume requiring treatment. The VCM treatment timeframes are similar for both GP-5 alternatives (i.e. 40 years). The GP-5 (700 gpm) is also equally protective. Due to the fact that the GP-5 (700 gpm) scenario is more cost efficient, the GP-5 (975 gpm) pumping scenario was eliminated from further consideration.

Obviously the GP-2 scenario is more cost effective than either of the GP-5 pumping systems. There are also the following additional benefits:

- i) pumping GP-2 at 700 gpm will remove 25 lbs/day of chemicals as soon as pumping is started as compared to 2.8 lbs/day for a GP-5 700 gpm scenario (this is due to the proximity of GP-2 to the elevated TCE plume); and
- ii) GP-2 is located more directly downgradient of the HN-24 TCE source whereas if GP-5 were pumped, the TCE would be drawn to the west and unnecessarily be drawn throughout more of the aquifer.

Thus, the GP-5 (700 gpm) pumping scenario was not retained for further evaluation. The GP-2 scenario was then compared to the MW-52 area system.

The maximum allowable VCM concentration in groundwater from GP-2, prior to exceeding the Air Guide 1 criteria for a flow rate of 700 gpm was calculated to be 15 µg/L. Using this concentration, the computer simulations indicate the time period for supplemental VCM treatment is estimated to start in approximately 28 years, and will be required for a period of 5 years.

In accordance with the NCP (40 CFR 300.430) there are nine criteria (see Section 5.0) that must be evaluated as part of an FS. These are:

| | MW-52 | GP-2 |
|---|-------|------|
| Overall Protection of Human Health and the Environment | √ | √ |
| Compliance with ARARs | √ | √ |
| Long-Term Effectiveness and Permanence | √ | √ |
| Reduction of Toxicity, Mobility or Volume Through Treatment | √ | |
| Short-Term Effectiveness | √ | |
| Implementability | √ | √ |
| Cost | | √ |
| Agency Acceptance | NA | NA |
| Community Acceptance | NA | NA |

Note: NA-Not Applicable at this stage of the FS.

A comparison of the two pumping alternatives (GP-2 and MW-52) versus the nine criteria is shown above. A "check" indicates that the alternative meets the criteria or is more favorable than the other alternative.

Of these nine criteria, the threshold criteria are considered to be the following:

- i) overall protection of human health and the environment; and
- ii) compliance with ARARs.

Thus, the GP-2 and MW-52 pumping options were compared against these two criteria.

As shown on the summary table, both of the pumping options achieve the two threshold criteria. However, because the MW-52 system involves removal and treatment of VCM as soon as construction is complete, the ARARs (with respect to VCM) would be achieved more quickly. Additionally, greater protection to human health and the environment is offered by the MW-52 system because the VCM concentrations are reduced within 7.5 years as compared to 33 years. Thus, the MW-52 pumping system was selected for inclusion in this FS.

Alternative 3A also addresses the TCE, PCE, and TICs present within the VCM subplume. Pumping from within the VCM subplume in the vicinity of MW-52 would intercept and remove TCE, PCE, and TICs (if any) from the aquifer. As stated in Section 4.2.1, data from the predesign investigation show that TICs are currently not

present at MW-52. The pretreatment system (likely air stripping) would address the TCE and PCE, however, most of the TICs (if any were present) are too water soluble to be removed by air stripping. The TICs (if any) recharged to the aquifer in the treated water would be subject to additional microbial degradation during their second southerly passage through the aquifer from the Hooker/Ruco site to the vicinity of MW-52. Any increase in TIC concentration would stimulate an equivalent increase in the microbial population and thus in-situ treatment of TICs would remain effective.

This alternative is designed to reduce the VCM concentrations in the VCM subplume such that VCM treatment will not be required to be added to the Northrop IRM. Thus this alternative does not affect the operation of the Northrop IRM, but does however, rely on it. The role of the Northrop IRM in Alternative 3A is that of a backup system. It will protect against the migration of VCM (above MCLs) beyond the IRM extraction wells to the downgradient public water supply wells.

The pump and treat component of Alternative 3A that is being used for mass removal of VCM is expected to operate for 5 years. Thus, the operating period for this component is considered short. The pump and treat component of Alternative 3A which will be provided by the Northrop IRM will operate for 50 years. This is defined as very long.

4.2.3.2 ALTERNATIVE 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE TO ACHIEVE GROUNDWATER ARARs

Alternative 3B is essentially the same as Alternative 3A, with the exception that the MW-52 area system will operate until the VCM concentration in the vicinity of MW-52 (i.e., at SPPW-1) achieves the MCL of 2 µg/L for VCM. Additionally, the MW-52 area system will prevent the migration of VCM with concentrations above the MCL beyond SPPW-2 and SPPW-3. The treatment methodology selected and treated groundwater disposal method will be the same as for Alternative 3A.

VCM simulations were conducted for Alternative 3B to evaluate the MW-52 area system pumping rates required to prevent VCM migration beyond SPPW-2 and SPPW-3 at levels greater than the MCL. The results of the VCM migration simulations are presented in Section 3.4 of Appendix A. It was determined that pumping rates of 250 gpm were required from both SPPW-2 and SPPW-3, in conjunction with a 500 gpm pumping rate from SPPW-1, to contain VCM within the MW-52 area. The VCM simulation demonstrated that the VCM concentrations in the MW-52 area are reduced to levels below the MCL in approximately 30 years. VCM concentrations significantly

above the MCL did not migrate downgradient of SPPW-2 or SPPW-3. By containing the VCM within the MW-52 area, supplemental VCM treatment is not required at GP-1. The same VCM monitoring program including frequencies described for Alternative 3A would be applied for Alternative 3B.

TCE, PCE, and TICs would be addressed as described for Alternative 3A. The longer pumping duration would be more effective in addressing any possible PCE, TCE and TICs remaining in the aquifer.

This alternative reduces VCM concentrations such that MCLs are achieved and thus VCM treatment will not be required to be added to the Northrop IRM. Thus this alternative does not affect the operation of the Northrop IRM and does not rely on it as a part of the remedy.

Alternative 3B is expected to operate for approximately 30 years. Thus, the operating period is considered long.

4.2.4 IN SITU TREATMENT OF VCM SUBPLUME

Alternatives 4A, 4B, and 4C all involve treatment of the VCM subplume by in situ methods. For all three alternatives, VCM treatment will be performed until VCM concentrations are reduced so that supplemental VCM treatment will not be required at the Northrop IRM. The three alternatives are:

- Alternative 4A - Enhanced Aerobic Bioremediation;
- Alternative 4B - Chemical Oxidation; and
- Alternative 4C - Biosparging.

Alternatives 4A, 4B, and 4C are discussed in detail in Sections 4.2.4.1, 4.2.4.2, and 4.2.4.3, respectively.

As presented in Section 3.4.4.7, all of the in situ alternatives in this FS are discussed with respect to the use of vertical wells as the injection delivery system.

A full scale in situ treatment system would be constructed in stages. The first stage would be a limited series of injection wells and monitoring wells which would be used to test and refine the injection parameters. The initial operation of the first stage will confirm design parameters such as injection well spacing, injection material ratios and

operating pressures. This staged approach would lead to the implementation of the full scale system using the design refinements obtained from the first stage installation.

Preliminary evaluation has shown biosparging to be the most likely in situ treatment to be used. The first stage of the biosparging remediation process was described in detail in a June 11, 1999 letter "Proposed Predesign Investigation Activities, Hooker/Ruco Site Operable Unit-3", specifically in Attachment A of said letter "Phase I Interim Remedial Measure Plan". The following is a brief summary of the June 11 letter.

The first stage testing of the biosparging technology will consist of the following tasks:

- | | |
|--------|--|
| Task 1 | Well Construction |
| Task 2 | Preliminary Testing using Existing Wells |
| Task 3 | Operation and Evaluation of the Phase I IRM Biosparging System |

Task 1 is the installation of groundwater and vadose zone monitoring wells and the two injection wells. The groundwater monitoring wells will monitor multiple intervals to better correlate the VCM distribution within the Site's hydrogeologic character. Following the installation and groundwater sample collection and analysis of the first five groundwater monitoring wells and the preliminary testing described in Task 3, the remaining two groundwater monitoring wells will be installed in conjunction with the installation of the two injection wells.

The primary intent of Task 2 will be to estimate the pneumatic properties of the formation by measuring sparge pressure and air flowrate and by conducting helium tracer testing. Dissolved oxygen (DO) in groundwater and oxygen and carbon dioxide in soil vapor (O_2/CO_2) will also be monitored to allow a preliminary assessment of the ability of sparging to oxygenate groundwater and to increase respiration rates in the vadose zone. The most effective way to obtain the necessary data is through the use of existing wells to gain as much site-specific knowledge as possible before initiating any injection well construction program.

Task 3 will utilize the constructed wells to initially evaluate biosparging. This testing will provide information on air injection parameters and also will provide full-scale assessment of the effectiveness of a biosparging system. This assessment will in turn guide the selection, construction, and operation of a possible final system. While the assessments are going on, the testing will provide the added benefit of actively remediating a portion of the VCM subplume. Chemical data will be collected during this phase to determine how effective this technology is as a remedy.

The schedule submitted with the June 11 letter shows that the above tasks would be completed in approximately eight months after approval from the USEPA. The benefits of performing the first stage testing under actual field conditions includes:

i) Better Hydrogeologic Information and VCM Subplume Definition:

ii) Immediate VCM Concentration Reductions:

Because the injection locations would be within the VCM subplume, the first stage testing would immediately result in actual VCM concentration decreases in the aquifer; and

iii) Cost Savings:

The first stage testing injection locations would be incorporated in the full scale treatment system, thus eliminating duplicate drilling efforts.

4.2.4.1 **ALTERNATIVE 4A: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION**

Alternative 4A involves reducing the VCM subplume concentrations by enhanced aerobic bioremediation. Similar to Alternative 3A, VCM concentrations would be reduced to levels such that supplemental VCM treatment is not required for the Northrop IRM. Enhanced aerobic bioremediation would be performed by injecting the necessary inorganic sources of nitrogen and phosphorous, along with suitable carbon sources (methane, etc.) to enhance the growth and metabolic activities of indigenous microbial populations and subsequently the degradation of VCM in the affected aquifer interval (approximately 250 to 360 feet bgs). The addition of nutrients to stimulate the microbial population will also enhance the degradation of TCE, PCE, and TICs. Therefore, this alternative will also effectively treat TCE, PCE, and TICs.

This alternative is designed to reduce VCM concentrations, to the point that supplemental treatment for VCM at the Northrop IRM is not required. VCM treatment could still be added to the Northrop IRM if the residual VCM concentrations did not continue to reduce as planned before the groundwater reaches GP-1. In addition, since PCE and TCE are slow to degrade in aerobic conditions, the Northrop IRM may be needed to address chemicals other than just the residual VCM. Thus, this alternative may potentially affect the operation of the Northrop IRM. As a result, the Northrop IRM is considered to be an active component of the remedy for the VCM subplume. It will protect against the migration of VCM and other VOCs present (above MCLs) beyond the IRM extraction wells to the downgradient public water supply wells.

As discussed in Section 3.4.4.7, vertical monitoring wells have been selected at this time to serve as the injection system for the in situ treatment options. For liquid injections (alternatives 4A and 4B) it is proposed to install 15 vertical injection location points throughout the VCM subplume. Nine injection locations would be installed in an east/west line near the southern plume boundary and would serve primarily as 'polishing' locations to ensure treatment goals are achieved. The other six injection locations would be interspersed throughout the area of elevated VCM concentrations. For gas injections (alternative 4C) 12 vertical injection points would be needed, six locations would be installed in an east/west line across the southern plume boundary and six injection locations would be interspersed throughout the area of elevated VCM concentrations. Proposed injection locations for Alternatives 4A and 4B, are shown on Figure 4.7 and proposed injection locations for Alternative 4C are shown on Figure 4.8.

Both liquids (Alternative 4A and Alternative 4B) and gas (Alternative 4C), can be delivered to the VCM affected portion of the aquifer using vertical wells. For liquid injection, a truck would be purchased and each of the 15 injection locations would be used periodically (i.e., monthly, bimonthly, quarterly) for injections. For gas injections, the injection locations would be connected together to a few centralized locations. The gas would be injected into the wells using a compressor at the centralized locations.

Because VCM is best degraded under aerobic conditions, it may be necessary to increase the concentrations of dissolved oxygen in the groundwater. This would be achieved by biosparging and/or the use of intercepting socks containing oxygen releasing compounds. As previously mentioned, neither PCE nor TCE degrade rapidly under aerobic conditions, therefore the Northrop IRM will be relied upon as an active component of the remedial system to treat any residual PCE, TCE, and VCM that is not treated by this alternative.

Similar to the other alternatives, sentry monitoring for VCM will be required for Alternative 4. VCM sentry monitoring is proposed to be performed at ten existing wells (MW-52 S, I, and D; MW-53I; D1 and D2; GM-12I; and GM-23S, I, and D; (see Figure 4.2) and the two new well nests (MW-58 and MW-59). Well nest MW-52 is the well with the highest VCM concentration and was selected to observe the trend in VCM concentrations. Well nest MW-53, at which VCM has not been detected, was selected to monitor the groundwater west of the VCM presence. Wells GM-12I, GM-23S, GM-23I, GM-23D, MW-58, and MW-59 were selected to observe if VCM is migrating southward beyond the VCM source control wells at concentrations which may require supplemental VCM treatment at GP-1. The sampling frequency will be the same as that described in Section 4.2.2 for Alternative 2.

As previously stated, the design would be implemented in stages to fine tune the final injection and delivery system prior to implementing a full scale version of Alternative 4A. Since the VCM subplume is only migrating at a rate of approximately 60 feet per year, there is a window of opportunity in which to complete the remediation in these appropriate stages.

The in situ component of Alternative 4A that is being used for mass removal of VCM is expected to operate for 7 to 10 years. Thus, the operating period for this component is short to medium. The pump and treat component of Alternative 4A which will be provided by the Northrop IRM will operate for 50 years. This is defined as very long.

4.2.4.2 ALTERNATIVE 4B: IN SITU TREATMENT OF VCM SUBPLUME BY CHEMICAL OXIDATION

Alternative 4B involves significantly reducing the VCM subplume concentrations, to approximately 40 µg/L, in the immediate vicinity of MW-52 (i.e., center of plume) by chemical oxidation. It is expected that chemical oxidation will be most effective to reduce chemical concentration to a level of approximately 100 µg/L. Below this concentration, it may be necessary to use enhanced aerobic bioremediation to reduce the VCM concentrations to approximately 40 µg/L. Similar to Alternatives 3A and 4A, VCM concentrations would be reduced to levels such that supplemental VCM treatment is not required for the Northrop IRM. If required, the enhanced aerobic bioremediation phase would occur near the south end of the VCM subplume using the nine 'polishing' locations, as described in Section 4.2.4.1. Chemical oxidation would be performed by injecting potassium permanganate into the affected aquifer interval, approximately 250 to 360 feet bgs, in the middle of the VCM subplume, where VCM concentrations are highest (on the order of 1,000 µg/L). The purpose of utilizing chemical oxidation prior to enhanced aerobic bioremediation is to significantly reduce the VCM concentrations in the center of the VCM subplume. The permanganate solution would be introduced into the aquifer using the 15 vertical monitoring injection locations discussed in Section 4.2.4.1.

The chemical oxidants will oxidize all organic compounds present, therefore, this alternative will also effectively treat TCE, PCE, and any TICs present that come in contact with the potassium permanganate.

This alternative is designed to reduce VCM concentrations, to the point that supplemental treatment for VCM at the Northrop IRM is not required. VCM treatment could still be added to the Northrop IRM if the residual VCM concentrations did not

continue to reduce as planned before the groundwater reaches GP-1. Thus, this alternative may potentially affect the operation of the Northrop IRM. As a result, the Northrop IRM is considered to be an active component of the remedy for the VCM subplume. It will protect against the migration of VCM and other VOCs present (above MCLs) beyond the IRM extraction wells to the downgradient public water supply wells.

The actual spreading of permanganate through the formation would be impacted by the effects of local-scale heterogeneities in the aquifer (i.e., inter-layered and discontinuous clay lenses), the density effects on the migration of permanganate in the aquifer and the amount of carbon compounds in the formation. While modeling could be used to estimate the extent of permanganate migration, this would be best measured in the field under actual conditions.

One concern with the use of potassium permanganate is the impact of the trace levels of metal impurities in the potassium permanganate on the groundwater. As part of the remedy for another component of the Hooker/Ruco Site (i.e., Operable Unit 1), it is planned to perform soil column tests to determine the solubility and the mobility of the metals present in potassium permanganate through the aquifer soils. The results of the tests will be used to evaluate the impact of the use of potassium permanganate on metals concentrations in the groundwater. It is expected that the metals will be adsorbed relatively quickly and will not be a concern.

Similar to the other alternatives, sentry monitoring for VCM will be required for Alternative 4B. VCM sentry monitoring is proposed to be performed at ten existing wells (MW-52 S, I, and D; MW-53I; D1 and D2; GM-12I; and GM-23S, I, and D; (see Figure 4.2) and the two new well nests (MW-58 and MW-59). Well nest MW-52 is the well with the highest VCM concentration and was selected to observe the trend in VCM concentrations. Well nest MW-53, at which VCM has not been detected, was selected to monitor the groundwater west of the VCM presence. Wells GM-12I, GM-23S, GM-23I, GM-23D, MW-58, and MW-59 were selected to observe if VCM is migrating southward beyond the VCM source control wells at concentrations which may require supplemental VCM treatment at GP-1. The sampling frequency will be the same as that described in Section 4.2.2 for Alternative 2.

As previously stated, the design would be implemented in stages to fine tune the final injection and delivery system prior to implementing a full scale version of Alternative 4B. Since the VCM subplume is only migrating at a rate of approximately 60 feet per year, there is a window of opportunity in which to complete the remediation in these appropriate stages.

The in situ component of Alternative 4B that is being used for mass removal of VCM is expected to operate for 3 to 5 years. Thus, the operating period for this component is very short. The pump and treat component of Alternative 4B which will be provided by the Northrop IRM will operate for 50 years. This is defined as very long.

4.2.4.3 ALTERNATIVE 4C: IN SITU TREATMENT OF VCM SUBPLUME BY BIOSPARGING

Alternative 4C involves reducing the VCM subplume concentrations by biosparging. If deemed necessary, the VCM concentrations could be further reduced, by enhanced bioremediation following the biosparging treatment. Similar to Alternatives 3A, 4A, and 4B, VCM concentrations would be reduced to levels such that supplemental VCM treatment is not required for the Northrop IRM (i.e., on the order of 40 µg/L). If required, the enhanced bioremediation phase would occur near the south end of the VCM subplume, as described in Section 4.2.4.1 using the six 'polishing' locations. Biosparging would be performed by injecting air into the affected aquifer interval, using the 12 vertical injection locations. Reduction of the VCM subplume concentrations by biosparging can be enhanced with injection of nutrients to promote aerobic degradation.

This alternative utilizes biosparging to treat VCM. Biosparging is the introduction of oxygen into the aquifer to enhance aerobic conditions and increase the microbial population. Aerobic conditions will result in an increased microbial population which will also enhance the degradation of the TICs. Aerobic conditions would not enhance the degradation of TCE and PCE therefore the effect of biosparging on TCE and PCE will be limited. The Northrop IRM is a pump and treat system designed to treat TCE and PCE, therefore, any residual TCE and PCE from the Hooker/Ruco Site remaining in the aquifer will be treated when captured by the Northrop IRM.

This alternative is designed to reduce VCM concentrations, to the point that supplemental treatment for VCM at the Northrop IRM is not required. VCM treatment could still be added to the Northrop IRM if the residual VCM concentrations did not continue to reduce as planned before the groundwater reaches GP-1. In addition, since PCE and TCE are slow to degrade in aerobic conditions, the Northrop IRM may be needed to address chemicals other than just the residual VCM. Thus, this alternative may potentially affect the operation of the Northrop IRM. As a result, the Northrop IRM is considered to be an active component of the remedy for the VCM subplume. It will protect against the migration of VCM and other VOCs present (above MCLs) beyond the IRM extraction wells to the downgradient public water supply wells.

As with Alternative 4B, the actual spreading of air through the formation would be impacted by the effects of local-scale heterogeneities in the aquifer (i.e., inter-layered and discontinuous clay lenses). While modeling could be used to estimate the extent of air dispersion, this would be best measured in the field, under actual conditions as proposed in the June 11, 1999 letter.

As to the other alternatives, sentry monitoring for VCM will be required for Alternative 4C. VCM sentry monitoring is proposed to be performed at ten existing wells (MW-52 S, I, and D; MW-53I; D1 and D2; GM-12I; and GM-23S, I, and D; (see Figure 4.2) and the two new well nests (MW-58 and MW-59). Well nest MW-52 is the well with the highest VCM concentration and was selected to observe the trend in VCM concentrations. Well nest MW-53, at which VCM has not been detected, was selected to monitor the groundwater west of the VCM presence. Wells GM-12I, GM-23S, GM-23I, GM-23D, MW-58, and MW-59 were selected to observe if VCM is migrating southward beyond the VCM source control wells at concentrations which may require supplemental VCM treatment at GP-1. The sampling frequency will be the same as that described in Section 4.2.2 for Alternative 2.

As previously stated, the design would be implemented in stages to fine tune the final injection and delivery system prior to implementing a full scale version of Alternative 4C. Since the VCM subplume is only migrating at a rate of approximately 60 feet per year, there is a window of opportunity in which to complete the remediation in these appropriate stages.

The in situ component of Alternative 4C that is being used for mass removal of VCM is expected to operate for approximately 3 years. Thus, the operating period for this component is very short. The pump and treat component of Alternative 4C which will be provided by the Northrop IRM will operate for 50 years. This is defined as very long.

5.0 DETAILED ANALYSIS OF ALTERNATIVES

5.1 INTRODUCTION

This section presents an evaluation of each alternative with respect to the criteria of the NCP of 40 CFR Part 300, as revised in 1990. The criteria as required by the NCP and the relative importance of these criteria are described in the following subsections.

5.1.1 EVALUATION CRITERIA

The evaluation criteria according to the NCP (40 CFR 300.430) are as follows:

Overall Protection of Human Health and the Environment

Alternatives must be assessed for adequate protection of human health and environment in both short and long term, from unacceptable risks posed by hazardous substances, or chemicals present at the site by eliminating, reducing, or controlling exposure to levels exceeding remediation goals. Overall protection draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Alternatives must be assessed to determine whether they attain ARARs under federal environmental laws and state environmental or facility siting laws. If one or more regulations that are applicable cannot be complied with, then a waiver must be invoked. Grounds for invoking a waiver would depend on the following:

- the alternative is an interim measure and will become part of a total remedial action that will attain the ARAR;
- compliance will result in greater risk to human health and the environment;
- compliance is technically impracticable from an engineering perspective;
- the alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach;
- a state requirement has not been consistently applied, or the state has not demonstrated the intention to consistently apply the promulgated requirement in similar circumstances at other remedial actions within the state; and

- for Fund-financed response actions only, an alternative that attains the ARAR will not provide a balance between the need for protection of human health and the environment at the site and the availability of Fund monies to respond to other sites that may present a threat to human health and the environment.

Long-term Effectiveness and Permanence

Alternatives must be assessed for the long-term effectiveness and permanence they offer, along with the degree of certainty that the alternative will prove successful. Factors that shall be considered as appropriate include the following:

Magnitude of Residual Risk:

Risk posed by untreated waste or treated waste residuals at the conclusion of remedial activities. The characteristics of residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.

Adequacy and reliability of controls:

Controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste must be shown to be reliable. In particular, the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment for the potential need to replace technical components of the alternative such as a cap, a slurry wall, or a treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement.

Reduction of Toxicity, Mobility, or Volume through Treatment

The degree to which the alternative employs recycling or treatment that reduces the toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed by the site. Factors that shall be considered, as appropriate, include the following:

- the treatment or recycling processes the alternative employs and the materials that they will treat;
- the amount of hazardous substances, pollutants, or chemicals that will be destroyed, treated, or recycled;

- the degree of expected reduction in toxicity, mobility or volume of waste due to treatment or recycling and the specification of which reduction(s) are occurring;
- the degree to which the treatment is irreversible;
- the type and quantity of residuals that will remain following treatment considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents; and
- the degree to which treatment reduces the inherent hazards posed by principal threats at the site.

Short-Term Effectiveness

The short-term impacts of the alternative shall be assessed considering the following:

- short-term risks that might be posed to the community during implementation;
- potential impacts on workers during remedial action and the effectiveness and reliability of protective measures;
- potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation; and
- time until protection is achieved.

Implementability

The ease or difficulty of implementing the alternatives shall be assessed by considering the following types of factors, as appropriate:

- technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy;
- administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-site actions); and
- availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and availability of prospective technologies.

Cost

Capital costs shall include both direct and indirect costs. Annual O&M costs shall be provided. A net present value of the capital and O&M costs shall also be provided. Typically cost estimate accuracy range is plus 50 percent to minus 30 percent.

Agency Acceptance

The state and federal agency concerns that must be assessed include the following:

- the agencies' position and key concerns related to the preferred alternative and other alternatives; and
- agency comments on ARARs or the proposed use of waivers.

These concerns cannot be fully evaluated at this time until the agencies have reviewed and commented on the OU-3 RI Report and this FS.

Community Acceptance

This assessment consists of responses of the community to the proposed plan. This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about, or oppose. This assessment can be done after comments on the proposed plan are received from the public.

5.1.2 RELATIVE IMPORTANCE OF CRITERIA

Among the nine criteria, the threshold criteria are considered to be the following:

- overall Protection of Human Health and the Environment; and
- compliance with ARARs (excluding those that may be waived).

The threshold criteria must be satisfied in order for an alternative to be eligible for selection.

Among the remaining criteria, the following five criteria are considered to be the primary balancing criteria:

- long-term effectiveness and permanence;
- reduction of toxicity, mobility and volume;
- short-term effectiveness;
- implementability; and
- cost.

The balancing criteria are used to weigh the relative merits of alternatives.

The remaining two of the nine criteria, namely Agency Acceptance and Community Acceptance are considered to be modifying criteria that must be considered during remedy selection. These last two criteria can be evaluated after the document has been reviewed by the EPA and State and the proposed plan has been discussed in a public meeting with the BWD community. Therefore, this document addresses only seven out of the nine criteria.

5.1.3 SELECTION OF REMEDY

The selection of a remedy is a two-step process. The first step consists of identification of a preferred alternative and presentation of the alternative in a proposed plan to the EPA and then to the BWD community for review and comment. The preferred alternative must meet the following criteria:

- protection of human health and the environment;
- compliance with ARARs unless a waiver is justified;
- cost effectiveness in protecting human health and environment and in complying with ARARs; and
- utilization of permanent solutions and alternate treatment technologies or resource recovery technologies to the maximum extent practicable.

The second step consists of the review of the comments and determination of whether the preferred alternative continues to be the most appropriate remedial action for the site, in consultation with the EPA and State.

5.2 DETAILED ANALYSIS

5.2.1 ALTERNATIVE 1: NO FURTHER ACTION - NORTHROP IRM (NO VCM TREATMENT)

Alternative 1 is a no further action remedial alternative that would include no pumping and/or treating of groundwater and no monitoring of municipal well fields other than those pumping and monitoring programs currently in place. For the purposes of this assessment it is assumed that no VCM treatment would be put in place at the Northrop IRM.

Overall Protection of Human Health and the Environment

Alternative 1 would provide no additional protection to human health from migration of VCM from the MW-52 area. The BWD wells currently being treated would continue to be treated, thus continuing to protect those well users. No additional groundwater monitoring would be performed to assess the migration of the VCM subplume other than those currently in place for the Northrop IRM. This alternative provides no protection to the Northrop IRM beyond the sentry monitoring program which checks upon the progression of the VCM subplume toward the Northrop IRM wells and provides an early warning of VCM presence. Prohibition of private well placement would protect the health of current and potential future users. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-Specific ARARs:

Natural processes may ultimately reduce the VCM concentrations in the MW-52 area subplume, to achieve to the extent feasible the New York State Groundwater Standards and MCLs (as regulated under 10 NYCRR Part 5 for a public water supply) which are applicable regulatory requirements for the sole-source aquifer under Long Island. It is difficult to determine if natural attenuation alone would achieve these objectives and the time duration that would be required. However, it is expected that treatment would be required at the Northrop IRM to address VCM presence in the air stripper off gas.

Action-Specific ARARs:

As Alternative 1 is essentially a no action alternative there are no action specific ARARs to be discussed.

Long-Term Effectiveness and Permanence

Magnitude of Residual Risk:

Alternative 1 would intercept groundwater with elevated VCM presence however, insufficient treatment would occur. The existing IRM treatment system removes the VCM from the water but does not effectively handle the VCM in the off gas from the treatment plant. Thus there is a risk that the Air Guide 1 criteria for VCM may be exceeded at the Northrop IRM. The aquifer will eventually attain VCM levels because the Northrop IRM contains, collects, and treats the VCM subplume, however the duration will be very long. No additional monitoring would be performed, thus the Northrop IRM is at risk of being unable to meet the Air Guide criteria.

Adequacy and Reliability of the Remedy:

Alternative 1 may not be adequate. The VCM subplume would be contained by the Northrop IRM but not effectively treated as the Northrop IRM does not currently have the installed technology to treat VCM off gases.

Reduction of Toxicity, Mobility, and Volume

Alternative 1 would not initially reduce VCM toxicity as groundwater with elevated VCM chemical presence would not be extracted until it reaches the Northrop IRM. The existing levels of toxicity and volume and current mobility in the area of the VCM subplume would not be reduced other than by natural attenuation.

Short-Term Effectiveness

Risks to Workers and Community:

Because this is essentially a no-action alternative, there would be no risk to workers. The community would be at risk through the possible exceedance of Air Guide 1 standards at the Northrop IRM.

Environmental Impacts:

The no further action alternative would not have adverse impacts on the environment from remedial action activities. Environmental impacts would result from not addressing the VCM subplume which would migrate toward and potentially reach the Northrop IRM.

Time Until Remedial Action Objectives are Attained:

The length of time that would be required for the aquifer to attain the RAO's via natural attenuation is lengthy but unknown (i.e., greater than 50 years).

Implementability

Technical Feasibility:

The no further action alternative is technically feasible.

Administrative Feasibility:

The no further action alternative would not be administratively feasible. Current administrative laws (Air Guide 1) and statutes make implementation of this alternative unacceptable.

Availability of Services and Materials:

Alternative 1 does not require services or materials.

Cost:

Because Alternative 1 is a no action alternative, there are no capital costs associated with this alternative.

Because Alternative 1 relies on the Northrop IRM for treatment of the VCM subplume, it is appropriate that the O&M cost of running the Northrop IRM should be shared between the VOC plume and the VCM subplume.

Although GSHI has developed a cost sharing methodology, the EPA has suggested that the determination of an appropriate cost sharing allocation between the TVOC plume and VCM subplume should not be included in this Feasibility Study. Such a

determination needs to include a complete evaluation of all of the factors that impact the operation of the Northrop IRM. These factors include but are not limited to:

- the concentrations of chemicals;
- the mass of chemicals;
- impact on the treatment process;
- travel time to reach the extraction points; and
- duration of the need for treatment.

Since it is now beyond the scope of this Feasibility Study to make this determination, and at the request of the EPA, the entire cost of the Northrop IRM has been included in the cost comparison for each of the alternatives that rely on the Northrop IRM as a part of the final remedy. The Northrop IRM cost amounts to \$56,000,000 which includes the expended costs to date, the capital costs, and O&M costs for the next 30 years. The portion of the total \$56,000,000 Northrop IRM cost that is to be allocated to OxyChem is indeterminate at this time but is expected to be minor.

5.2.2 **ALTERNATIVE 2: ENHANCED NORTHROP IRM (SUPPLEMENTAL VCM TREATMENT IF NECESSARY)**

Alternative 2 consists of the continued operation of the Northrop IRM system to address the regional VOC plume and the use of monitoring to determine if future supplemental treatment for VCM is necessary at well GP-1. The Northrop IRM system is a pump-and-treat system consisting of four extraction wells (ONCT-1, ONCT-2, ONCT-3 and GP-1) and above-ground treatment systems. Monitoring would be used to assess the migration of VCM toward the Northrop IRM and to verify that RAOs are met. Groundwater modeling of the VCM subplume confirms that complete containment of the VCM subplume is achieved by the Northrop IRM. Institutional controls would consist of Nassau County maintaining New York State's restrictions on the use of private wells or placement of new private wells in the aquifer. The BWD would continue to supply potable water to consumers in the vicinity of the three sites. Natural attenuation by aerobic degradation of the VCM might reduce the concentration of VCM. Greater detail was provided on this alternative in Section 4.2.2.

Overall Protection of Human Health and the Environment

Alternative 2 would be protective of human health because groundwater monitoring would be employed to assess the migration of the VCM subplume to determine whether

and/or when supplemental treatment of the extracted groundwater was needed to address VCM presence. Alternative 2 would also be protective of the Northrop IRM because groundwater monitoring would be used to determine when or if future supplemental treatment of the IRM air discharge for VCM would be necessary. Any usage of the groundwater within the VOC plume or VCM subplume by industrial users would necessitate the inclusion of an appropriate treatment technology prior to use. Prohibition of private well placement would protect the health of current and potential future users. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 2, similar to Alternative 1, would ultimately reduce the VCM groundwater concentration from the MW-52 area to achieve to the extent feasible the New York State Groundwater Standards and MCLs (as regulated under 10 NYCRR Part 5 for a public water supply) which are applicable regulatory requirements for the sole-source aquifer under Long Island. The VCM would continue to migrate until it was intercepted by the Northrop IRM system.

Action-specific ARARs:

The extraction and treatment of the groundwater is being conducted in accordance with the action specific ARARs that were identified in Section 3.2.3.3. The use of vapor-phase activated carbon for off-gas treatment meets New York Air Pollution Control Regulations (6 NYCRR Parts 200-254) for a BACT for VOCs under Rating A. The concentrations of VOCs in the treated groundwater are less than the New York State MCLs and therefore, recharge is within the concentration limits of the New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700-705) for Class GA groundwater. Treatment of the groundwater would meet SPDES standards for discharge on site. If supplemental VCM treatment is required in the future, catalytic oxidation of off-gases (or an appropriate alternative as determined at that time) will be required to meet the New York Air Pollution Control Requirements. VCM groundwater MCLs would also be met to allow for continued discharge of treated groundwater to the aquifer.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk:

Because Alternative 2 will intercept all areas of groundwater with elevated VCM presence, the remedy offers minimal residual risk. Although the risk remains for the time period and over the area until the VCM reaches the Northrop IRM, the risk slowly dissipates. Some areas of the aquifer will eventually attain concentrations corresponding to acceptable risk level ARARs via natural attenuation, by dilution, aerobic biodegradation, etc. The attainment of acceptable risk levels through natural attenuation is expected to occur but over an extended duration. The use of groundwater monitoring will be effective in determining when or if future supplemental treatment for VCM at the Northrop IRM wells is necessary. During the time period that the VCM subplume migrates to the Northrop IRM, the residual risk to potential industrial users within the VCM plume can be controlled to acceptable levels.

Adequacy and Reliability of the Remedy:

Because the VCM from the area of well MW-52 will be contained by Alternative 2, it is likely that the VCM subplume will affect the Northrop IRM extraction well system. The IRM treatment system removes VOCs from water by air stripping, followed by capture of the VOCs in a vapor-phase activated carbon adsorber. However, because activated carbon adsorption is ineffective in capturing VCM, the off-gas emissions could contain VCM at levels that may violate Air Guide 1 criteria. If the VCM is intercepted in the Northrop IRM extraction well system, then modifications to the Northrop IRM treatment system may be required, including, but not limited to the replacement of the activated carbon adsorber with a catalytic oxidation unit for off gas treatment. Monitoring for VCM will provide sufficient lead time to design and install supplemental VCM treatment without having to shut down the IRM system for a significant period of time. Therefore, Alternative 2 would be adequate and could be a permanent solution to address the VCM subplume.

Reduction of Toxicity, Mobility, and Volume

Alternative 2 would not initially reduce VCM toxicity as groundwater with elevated VCM chemical presence would not be extracted. Monitoring would ensure that appropriate treatment technologies could be put in place to reduce the toxicity, mobility, and volume of VCM once it reaches the Northrop IRM wells and would be treated, however the existing levels of toxicity and volume and current mobility in the formation would not be reduced other than by natural attenuation.

Implementability

Technical Feasibility:

The additional technology required for Alternative 2: catalytic oxidation for off-gas treatment, has been demonstrated and proven effective for VCM. It is further expected that in 40 years, improved treatment technologies will also be available.

Administrative Feasibility:

There are no major concerns affecting the administrative feasibility of Alternative 2. Permit modifications would be required for the off-gas, if treatment for VCM becomes necessary.

Availability of Services and Materials:

The treatment plant is already constructed and operating. Facilities are available for disposal/recycling of the recovered concentrated solvent from the regeneration condensate.

Cost

Computer simulations show that supplemental treatment for VCM at GP-1 will be necessary starting in the order of 46 to 51 years. The estimated present worth cost for the treatment starting in 40 years and operating for a period of 30 years (using a discount rate of 5 percent) is \$330,000 for the off-gas treatment option of catalytic oxidation.

In addition, similar to Alternative 1, the reliance of Alternative 2 on the Northrop IRM for the treatment of the groundwater from the VCM subplume will result in a minor contribution needing to be made toward the \$56,000,000 cost of the Northrop IRM.

5.2.3 ALTERNATIVES 3A AND 3B: VCM SUBPLUME CONTAINMENT, TREATMENT, AND DISCHARGE

This section provides a detailed analysis for Alternatives 3A and 3B. Both of these alternatives, at a minimum, achieve the human health and environment protection, ARAR compliance, long-term effectiveness and permanence, reduction of toxicity, mobility, and volume of VCM, short-term effectiveness and implementability of those

Short-term Effectiveness

Risks to Workers and Community:

The risks to the workers and community, because of exposure to the off-gas emissions under Alternative 2, are minimal through the use of vapor-phase activated carbon adsorption on the air-stripper emissions. Monitoring for VCM provides adequate lead time to design and install supplemental treatment, if necessary, thereby controlling the risks to workers and the community because of exposure to off-gas emissions of VCM. Adequate operation and maintenance procedures for the treatment plant ensure that the potential for uncontrolled release of groundwater with elevated chemical presence to the environment or the community is minimized. The plant operators take appropriate housekeeping measures and follow health and safety guidelines to minimize any other risks. The existing on-site regeneration of spent activated carbon using steam is conducted under controlled conditions with appropriate safety measures and adequate alarms to minimize the possibility of exposure to high temperature steam and vapor-phase VOCs. Off-site recycling or disposal of the recovered VOC condensate is conducted at a suitable off-site facility that is adequately equipped to minimize any risks of release of the VOCs to the environment or the surrounding community.

Environmental Impacts:

The remedial action is not expected to have any adverse impacts on the environment. The contaminated areas under consideration are within an industrialized zone and there are no sensitive flora or fauna that have any potential to be adversely affected.

Time until Remedial Action Objectives are Attained:

Groundwater modeling results (Appendix A) indicate that the VCM subplume will take on the order of 46 to 51 years to migrate to the Northrop IRM treatment system. Simulations indicate that if VCM treatment commenced in 40 years, an operating period of 30 years would be required.

described for Alternative 2. A detailed description of each alternative is provided in Sections 4.2.3 and 4.2.4 for Alternatives 3A and 3B, respectively. These two Alternatives are discussed further below in terms of how the additional pumping from within the VCM subplume is beneficial.

**5.2.3.1 ALTERNATIVE 3A: VCM SUBPLUME
CONTAINMENT, TREATMENT, AND
DISCHARGE FOR VCM MASS REDUCTION**

Alternative 3A consists of the continued operation of the Northrop IRM system to address the regional VOC plume. The Northrop IRM system and components of institutional controls/monitoring/natural attenuation would be identical to those described under Alternative 2. Alternative 3A also includes the treatment of VCM in the vicinity of MW-52 to ensure that supplemental treatment for VCM at GP-1 is not necessary in the future. As discussed in Section 4.2.3, other pumping scenarios exist which also could address the VCM subplume and negate the potential need for supplemental treatment at the Northrop IRM. Alternative 3A, the MW-52 system was retained for the reasons outlined previously in Section 4.2.3. In summary, the alternative involves extraction of groundwater from within the VCM subplume in the vicinity of MW-52. The extracted groundwater would be treated until concentrations were achieved which, when pumping was terminated and residual VCM was allowed to migrate south to GP-1, would ensure that supplemental VCM treatment would not need to be added to the Northrop IRM.

Overall Protection of Human Health and the Environment

Alternative 3A provides protection to human health by removing sufficient VCM mass from the vicinity of MW-52 so that supplemental treatment for VCM at GP-1 will not be required in the future. The simulated maximum concentration at GP-1 was on the order of 5 µg/L. The estimated maximum allowable VCM concentration at GP-1 which ensures that off-gases meet the Air Guide 1 criteria is 8.3 µg/L (this concentration assumes that the existing air treatment system would retain no VCM. Since this is not the case, this concentration is a conservative estimate of the influent concentration at which supplemental treatment would be required). Thus, this alternative is protective of the Northrop IRM.

Groundwater monitoring as described in Section 3.2.2 will be performed to monitor the effectiveness of the MW-52 area extraction system in achieving the system objectives and ensure protection of human health and the environment. The areas to be impacted by

construction of the system are within an industrial area, which has no sensitive flora or fauna to be adversely impacted. Furthermore, there are no current groundwater users between the MW-52 area and the Northrop IRM wells. Alternative 3A would also be protective of the Northrop IRM but does allow low level chemical presence from the VCM subplume to be captured by the Northrop IRM after the large mass of VCM (and other chemicals in the VCM subplume) has been removed. Thus human health and the environment are protected. Prohibition of private well placement would protect the health of current and potential future users. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 3A involves VCM mass removal in the vicinity of MW-52. Class GA groundwater standard achievement at the groundwater extraction locations is not the goal, however, this remedy would ensure that VCM concentrations within the hydraulic influence of GP-1 are low enough so that the Air Guide 1 criteria for VCM ($0.02 \mu\text{g}/\text{m}^3$) is not exceeded. Thus, this remedy would fall under the category of an IRM with the final remedy being provided by the Northrop IRM System. Discharge of treated groundwater to recharge basins would also assist in the remediation of other chemicals present by providing additional flushing action.

Action-specific ARARs:

The extraction and treatment of the groundwater in the MW-52 area would be implemented in accordance with the action-specific ARARs that were identified in Section 3.2.3.3. The use of catalytic oxidation for off-gas treatment is expected to meet New York Air Pollution Control Regulations (6 NYCRR Parts 200 to 254) for a BACT for VOCs under Rating A. The concentrations of VOCs (including VCM) in the treated groundwater are expected to be less than the New York State MCLs and therefore, recharge would be within the concentration limits of the New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700 to 705) for Class GA groundwater. Treatment of the groundwater would meet SPDES standards for discharge back into the formation.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk:

Alternative 3A ensures that the areas of groundwater with detected VCM are intercepted and elevated VCM concentrations are immediately reduced, thus the residual risk is reduced.

Adequacy and Reliability of the Remedy:

Alternative 3A limits migration of VCM from the area of well MW-52 to the extent that future supplemental VCM treatment at GP-1 will not be required. Regarding the permanence of the system, it is planned that the MW-52 area system will only be operated for a limited period of time (i.e. approximately 5 years) until the VCM groundwater concentrations in SPPW-1 reduce to approximately 40 µg/L. Once this concentration has been achieved at SPPW-1, the potential for requiring supplemental VCM treatment at GP-1 is negligible. Therefore Alternative 3A would be a permanent, long-term effective solution.

Reduction of Toxicity, Mobility, and Volume

In addition to the reductions of toxicity, mobility and volume of VOCs in Alternative 2, the toxicity, mobility and volume of VCM is further reduced by limiting its continued southerly migration during the 5-year pumping period, which results in mass removal and reductions in VCM concentrations. The concentrations that remain after pumping stops will be reduced by natural attenuation. Groundwater with these reduced concentrations will be captured and treated by the Northrop IRM. The toxicity and mass are reduced by extracting and treating the groundwater.

Short-Term Effectiveness

Risks to Workers and Community:

The risks during construction of the groundwater extraction and treatment system will be minimized using appropriate health and safety measures. Risks to operators of the treatment system will be controlled through the use of appropriate operation and maintenance procedures. Treatment of the air stream by catalytic oxidation would protect the on-site workers and the community.

Environmental Impacts:

As discussed earlier, the affected areas are industrialized with no sensitive flora or fauna. Therefore, the potential for environmental impacts of the remediation is not significant.

Time until Remedial Action Objectives are Attained:

Groundwater modeling results (Appendix A) indicate that the VCM subplume would require pumping and treatment for approximately 5 years to ensure that the maximum VCM concentrations that reach GP-1 will be on the order of 5 µg/L.

This alternative is expected to achieve or be very close to achieving the RAOs by the time the remnants of the VCM subplume reach well GP-1 of the Northrop IRM. If further reduction in groundwater chemical concentrations are needed to achieve MCLs, such polishing would be performed by the Northrop IRM.

Implementability

Technical Feasibility:

The additional technology that would be used under Alternative 3A: catalytic oxidation for off-gas treatment, is demonstrated and proven to be effective for the VCM presence and any other VOCs. As stated in Section 4.2.1, data from the predesign investigation show that TICs are currently not present at MW-52. The pretreatment system (likely air stripping) would address the TCE and PCE, however, most of the TICs (if any were present) are too water soluble to be removed by air stripping. The TICs (if any) recharged to the aquifer in the treated water would be subject to additional microbial degradation during their second southerly passage through the aquifer from the Hooker/Ruco site to the vicinity of MW-52. Any increase in TIC concentration would stimulate an equivalent increase in the microbial population and thus in-situ treatment of TICs would remain effective.

Administrative Feasibility:

Administrative requirements will include obtaining property and/or property access for installation of the two proposed monitoring well nests (MW-58 and MW-59), the three pumping wells (SPPW-1, SPPW-2, and SPPW-3) as discussed in Section 4.2.3, and for the construction of the forcemain from the wells to the treatment system. This includes obtaining access to bore and jack under the railway line for the forcemain to go from the

extraction well locations to the proposed treatment facility location on the Hooker/Ruco Site. Local and state permits will also be required for the wells, forcemain, treatment facility, and recharge basin. The treatment facility would require permits for discharge of the treated groundwater and treated air. These permits should be obtainable.

Available of Services and Materials:

Groundwater extraction by pumping wells is already implemented in the area. As discussed in Section 3.4.4.3, available land is diminishing and may pose difficulty for locating extraction wells. The technology uses equipment readily available from several suppliers. A sufficient number of suppliers for the groundwater treatment system are available so that no difficulties in obtaining equipment are foreseen.

Operation requirements will include groundwater monitoring and treatment system operation (e.g., electrical, chemical, and operators). Maintenance would include repair/replacement of system components.

Cost

The estimated capital cost is approximately \$3,474,000.. The estimated O&M costs are approximately \$643,000 per year to \$691,000 per year. The present worth costs of this alternative, based on operating periods of 5, 7.5, and 10 years, and a discount factor of 5 percent are shown below:

| Operating Period (Years) | Present Worth Cost |
|-----------------------------|----------------------------|
| 5 | \$6,258,000 to \$6,465,000 |
| 7.5 | \$7,412,000 to \$7,706,000 |
| 10 | \$8,439,000 to \$8,810,000 |

The most likely operating period for this alternative is five years. For the most likely operating period, the present worth cost ranges from \$6,258,000 to \$6,465,000 not including the minor Northrop IRM O&M contribution.

The reliance of Alternative 3A on the Northrop IRM for the treatment of residual chemicals in the groundwater from the VCM subplume will result in a minor contribution needing to be made toward the \$56,000,000 cost of the Northrop IRM.

**5.2.3.2 ALTERNATIVE 3B: VCM SUBPLUME
CONTAINMENT, TREATMENT, AND DISCHARGE
TO ACHIEVE GROUNDWATER ARARs**

Alternative 3B is similar to Alternative 3A in that the same extraction wells and treatment methodology would be utilized. However, the extraction and treatment of groundwater will continue until monitoring shows that the VCM concentrations in the subplume are below the groundwater MCLs for VCM (2 µg/L). This will eliminate the possibility of needing supplemental VCM treatment at GP-1 and will reduce VCM concentrations in the vicinity of MW-52 to 2 µg/L as compared to approximately 40 µg/L as was required under Alternative 3A. To ensure that the VCM subplume is contained, increased pumping rates, as compared to Alternative 3A, are required. The pumping rates at SPPW-2 and SPPW-3 would be increased from 50 gpm to 250 gpm to hydraulically contain the southern limit of the subplume. The pumping rate for SPPW-1 (500 gpm) would not change.

Overall Protection of Human Health and the Environment

Alternative 3B, provides protection to human health by minimizing the migration of VCM subplume from the MW-52 area.

Alternative 3B provides slightly greater protection to human health in the area of the VCM subplume than the previous alternatives because the VCM subplume in the area of well MW-52 would be reduced to concentrations on the order of 2 µg/L. Similar to Alternative 3A, supplemental VCM treatment of GP-1 will not be required. In fact, Alternative 3B has no need for reliance on the Northrop IRM. Groundwater monitoring as described in Section 3.2.2 will be performed to monitor the effectiveness of the MW-52 area extraction system in achieving the system objectives and ensure protection of human health and the environment. The areas to be impacted by construction of the system are within an industrial area, which has no sensitive flora or fauna to be adversely impacted. Furthermore, there are no current groundwater users between the MW-52 area and the Northrop IRM wells. Alternative 3B would also be protective of the Northrop IRM. Prohibition of private well placement would protect the health of current and potential future users. Thus human health and the environment are protected. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 3B involves VCM mass removal in the vicinity of MW-52. Alternative 3B would reduce the concentration of VCM in the aquifer in the MW-52 area to achieve to the extent feasible the New York State MCLs (as regulated under 10 NYCRR Part 5 for a public water supply) which are applicable regulatory requirements for the sole-source aquifer under Long Island. Discharge of treated groundwater to recharge basins would also assist in the remediation of other chemicals present by providing additional flushing action.

Action-specific ARARs:

The extraction and treatment of the groundwater in the MW-52 area would be implemented in accordance with the action specific ARARs that were identified in Section 3.2.3.3. The use of catalytic oxidation for off-gas treatment is expected to meet New York Air Pollution Control Regulations (6 NYCRR Parts 200-254) for a BACT for VOCs under Rating A. The concentrations of VOCs in the treated groundwater are expected to be less than the New York State MCLs and therefore, recharge would be within the concentration limits of the New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700-705) for Class GA groundwater. Treatment of the groundwater would meet SPDES standards for discharge back into the formation.

Long-Term Effectiveness and Permanence

Magnitude of Residual Risk:

The magnitude of residual risk, as a result of the VCM subplume is less for Alternative 3B as compared to Alternatives 2 and 3A, through greater reductions in the toxicity, mobility, and mass of VCM in the immediate area of MW-52. Although Alternative 3B is incrementally better than Alternative 3A in that the toxicity, mass, and mobility of VCM is less, there are no additional benefits to human health or the environment. Monitoring for VCM presence for Alternatives 2 and 3A ensures that risks as a result of VCM are the same.

Adequacy and Reliability of Remedy:

Alternative 3B is expected to be adequate to treat the VCM subplume in the MW-52 area. There would be no adverse effect on the Navy and Northrop operations and on the

reliability of the Northrop IRM treatment system, because the VCM in the area of well MW-52 would be contained and the potential for this VCM to further migrate towards the Northrop IRM extraction wells, would be essentially eliminated. Computer modeling simulations show that treating the VCM to MCLs will require approximately 30 years of pumping. Therefore, Alternative 3B would be a permanent solution.

Reduction of Toxicity, Mobility, and Volume

VCM would be treated until the New York State MCL of 2 µg/L was achieved, thus reducing the toxicity, mobility, and volume of VCM. Treatment to the MCL prevents southerly migration of the VCM subplume.

Short-term Effectiveness

Risks to Workers and Community:

The risks during construction of the groundwater extraction and treatment system will be minimized using appropriate health and safety measures. Risks to operators of the treatment system will be controlled through the use of appropriate operation and maintenance procedures. Treatment of the air stream by catalytic oxidation protects the on-site workers and community.

Environmental Impacts:

As discussed earlier, the affected areas are industrialized with no sensitive flora or fauna. Therefore, the potential for environmental impacts of the remediation is not significant.

Time Until Remedial Action Objectives are Achieved:

Groundwater modeling results (Appendix A) indicate that the VCM subplume would require treatment for approximately 30 years to achieve VCM groundwater concentrations of 2 µg/L.

Implementability

Technical Feasibility:

The technical feasibility aspects for Alternative 3B are identical to those described for Alternative 3A. The technologies that would be used under Alternative 3B: extraction

wells, air stripping with catalytic oxidation, recharge basins etc., are demonstrated and proven to be effective for the VCM and other VOCs present.

Administrative Feasibility:

The administrative feasibility aspects of Alternative 3B are identical to those described for Alternative 3A. Administrative requirements will include obtaining property and/or property access for installation of the two proposed monitoring well nests (MW-58 and MW-59), the three pumping wells (SPPW-1, SPPW-2, and SPPW-3) and for the construction of the forcemain from the wells to the treatment system. This includes obtaining access to bore and jack under the railway line. Local and state permits will also be required for the wells, forcemain, treatment facility, and recharge basin. The treatment facility would require permits for discharge of the treated groundwater and treated air. These permits should be obtainable. Permits or permit modifications would be required for the air and treated groundwater discharge. These permits should be obtainable.

Availability of Services and Materials:

The availability of services and materials for Alternative 3B are identical to those described for Alternative 3A. Groundwater extraction by pumping wells is already implemented in the area. The technology uses equipment readily available from several suppliers. As discussed in Section 3.4.4.3, available land is diminishing and may pose difficulty for locating extraction wells. A sufficient number of suppliers for the groundwater treatment system are available so that no difficulties in obtaining equipment are foreseen.

Operation requirements will include groundwater monitoring and treatment system operation (e.g., electrical, chemical, and operators). Maintenance will include repair/replacement of system components.

Cost

The estimated capital cost is approximately \$4,195,000. The estimated O&M costs are approximately \$679,000 per year to \$722,000 per year. The present worth costs of the alternative, based on operating periods of 25, 30, and 35 years and a discount factor of 5 percent are shown below:

| Operating Period (Years) | Present Worth Cost |
|--------------------------------|------------------------------|
| 25 | \$13,765,000 to \$14,441,000 |
| 30 | \$14,633,000 to \$15,370,000 |
| 35 | \$15,313,000 to \$16,099,000 |

The most likely operating period for this alternative is 30 years.

5.2.4 **ALTERNATIVES 4A, 4B, AND 4C: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION/CHEMICAL OXIDATION/BIOSPARGING FOR VCM MASS REDUCTION**

This section provides a detailed analysis of Alternatives 4A, 4B, and 4C. All of these alternatives, at a minimum, achieve the human health and environment protection, ARAR compliance, long-term effectiveness and permanence, reduction of toxicity, mobility, and volume of VCM, short-term effectiveness and implementability of those described for Alternatives 2, 3A, and 3B. A detailed description of each alternative is provided in Sections 4.2.4.1, 4.2.4.2, and 4.2.4.3 for Alternatives 4A, 4B, and 4C, respectively. These three alternatives are discussed further in terms of how in situ treatment within the VCM subplume is beneficial.

5.2.4.1 **ALTERNATIVE 4A: IN SITU TREATMENT OF VCM SUBPLUME BY ENHANCED AEROBIC BIOREMEDIATION**

Alternative 4A would consist of treatment of the VCM subplume using in situ enhanced aerobic bioremediation. The components of Alternative 4A include: continued operation of the Northrop IRM system to address the on-site regional VOC plume and in situ treatment of the VCM subplume.

Overall Protection of Human Health and the Environment

Alternative 4A, provides additional protection to human health by minimizing the migration of VCM from the area around MW-52. Alternative 4A would also be protective of human health because groundwater monitoring would be employed to assess the migration of the regional VOC plume. Prohibition of private well placement would protect the health of current and future potential users. The other aspects

relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 4A would reduce the concentrations of VCM in the aquifer near MW-52. The VCM subplume in the MW-52 area would be remediated with the intent of achieving average VCM concentrations of approximately 40 µg/L to ensure that supplemental VCM treatment of air at GP-1 of the Northrop IRM is not required.

Action-Specific ARARs:

This treatment alternative requires the injection of inorganic sources of nitrogen/phosphorous with suitable carbon sources (methanol, methane, propane, etc.) into the groundwater. The exact nutrient requirement for VCM reduction is dependent on the presence of other constituents in groundwater, and would be determined during treatability studies. The first stage testing would also be used to determine whether there is any toxicity problems which may inhibit microbial growth and activity. The injection of nutrients into groundwater for full-scale treatment would need to be reviewed and approved in advance by the regulatory authorities. In addition to the injection of nutrients, it may be necessary to supplement the dissolved oxygen concentration in the groundwater. This could be achieved by either biosparging and/or the use of intercepting socks containing oxygen releasing compounds.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk:

The magnitude of residual risk, as a result of the VCM subplume is decreased by Alternative 4A through reductions in the toxicity, mobility, and mass of VCM. The mass of the VCM with highest concentrations would be reduced upon reaching the locations of nutrient addition.

Adequacy and Reliability of Remedy:

Alternative 4A is expected to be effective in treating the groundwater with elevated VCM presence. The introduction of nutrients into the groundwater is expected to enhance VCM biodegradation rates and achieve VCM aquifer concentrations on the

order of 40 µg/L. There would be limited short-term adverse effects to the environment as there would be no extraction and recharge of groundwater from/to the aquifer. There would be no adverse effect on the reliability of the Northrop IRM system because the VCM concentrations and mass from the area of well MW-52 would be significantly reduced. Therefore, Alternative 4A would be an adequate and permanent solution.

Reduction of Toxicity, Mobility, and Volume

Alternative 4A would reduce the toxicity and mass of VCM through the introduction of substrates and nutrients to enhance aerobic degradation in conjunction with in situ natural attenuative processes. Groundwater would be treated until an average VCM concentration of approximately 40 µg/L was achieved. The mass of the VCM within the regional VOC plume would be reduced as would the other VOCs and TICs (if any). The in situ method would remove a sufficient mass of VCM so that supplemental treatment of the GP-1 air discharge is not required. Any residual VCM that would not be treated by the in situ methodology would still be captured and treated by the Northrop IRM.

Short-Term Effectiveness

Risks to Workers and Community:

This alternative involves minimal invasive activities once the injection phase commences. Risks during installation of the nutrient delivery system would be minimized using appropriate health and safety measures. Risks to operators of the system will similarly be minimized.

Environmental Impacts:

As discussed earlier, the affected areas are industrialized with no sensitive flora or fauna. Therefore, the potential for environmental impacts of the remediation is not significant.

Time Until Remedial Action Objectives are Achieved:

The injection of substrates and nutrients associated with enhanced aerobic bioremediation is expected to be required for a period between 5 to 10 years. The duration is dependent on the time required for the VCM subplume to migrate south, past the nutrient addition locations. Increasing or decreasing the number of nutrient addition locations and the rate of injection will also affect the duration. It is to be noted that since this remedy partly relies on the natural flow of the groundwater to enter the

nutrient zone, and because the rate of flow is so slow (≈ 60 feet per year), it is not necessary to continuously inject nutrients. Nutrient addition can be done on a periodic basis (i.e., once per month, bimonthly, quarterly).

This alternative is expected to achieve or be very close to achieving the RAOs by the time the remnants of the VCM subplume reach well GP-1 of the Northrop IRM. If further reduction in groundwater chemical concentrations are needed to achieve MCLs, such polishing would be performed by the Northrop IRM.

Implementability

The limiting factor of Alternative 4A will be the ability of the delivering system to adequately distribute the nutrients throughout the VCM subplume. Lateral distribution will be considered adequate with the proper placement of the injection well system. Vertical distribution may be limited by hydraulic barriers, (e.g., clay layers) which can be overcome by proper design of the screen intervals of the injection wells and associated injection methods. Several nutrient sources suitable for the enhancement of VCM biodegradation are commercially available. Necessary injection permits would need to be obtained.

Permits would be required for the drilling of injection wells. These permits should be obtainable.

Due to the fact that the injections can be done on a periodic basis, the delivery of nutrients to the injection wells is easy to accommodate.

Availability of Service and Materials:

All the services, materials and equipment required for this treatment alternative are available from several subcontractors and suppliers.

Cost

The estimated capital cost is approximately \$1,566,000. The estimated O&M costs are approximately \$257,000 per year. The present worth costs using a discount factor of 5 percent for a time period of 5 and 10 years are shown below:

| Operating Period (Years) | Present Worth Cost |
|--------------------------------|--------------------|
| 5 | \$2,679,000 |
| 10 | \$3,551,000 |

The most likely operating period for the injection of substrates and nutrients associated with this alternative is 10 years. For the most likely operating period, the present worth is \$3,551,000, not including the minor Northrop IRM O&M contribution.

The reliance of Alternative 4A on the Northrop IRM for the treatment of residual chemicals in the groundwater from the VCM subplume will result in a minor contribution needing to be made toward the \$56,000,000 cost of the Northrop IRM.

5.2.4.2 **ALTERNATIVE 4B: IN SITU TREATMENT OF VCM SUBPLUME BY CHEMICAL OXIDATION**

Alternative 4B would consist of treatment of the VCM subplume using in situ chemical oxidation. The components of Alternative 4B include: continued operation of the Northrop IRM system to address the on-site regional VOC plume and in situ treatment of the VCM subplume using chemical oxidation. If deemed necessary or desirable, the chemical oxidation remedy could be enhanced by including bioremediation as a polishing step either through inclusion of Alternative 4A or 4C.

Overall Protection of Human Health and the Environment

Alternative 4B, provides protection to human health by minimizing the migration of VCM from the area around MW-52. Alternative 4B would also be protective of human health because groundwater monitoring would be employed to assess the migration of the regional VOC plume. Prohibition of private well placement would protect the health of current and future potential users. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 4B would reduce the concentrations of VCM in the aquifer near MW-52. The VCM subplume in the MW-52 area would be remediated with the intent of achieving average VCM concentrations of approximately 40 µg/L to ensure that supplemental VCM treatment of air discharge from GP-1 of the Northrop IRM is not required. Chemical oxidation would be performed to significantly decrease the VCM concentrations in the center of the subplume. This process would decrease VCM concentrations to approximately 100 µg/L with a goal of achieving approximately 40 µg/L. Below 100 µg/L, it may be more effective to use enhanced aerobic bioremediation to complete the remedy to concentrations on the order of 40 µg/L. The need for enhanced bioremediation would be determined following field implementation of the remedy.

Action-Specific ARARs:

This treatment alternative would require the injection of various additives to groundwater. The first phase of the treatment would involve the injection of potassium permanganate solution to groundwater over a period of approximately 3 years, during which time the groundwater would be monitored routinely. Although, the treatment is expected to convert a significant percentage of the VCM, the treatment period could be extended depending on the results. Based on the estimated volume of the groundwater impacted by VCM and the average VCM concentration, the total amount of injected permanganate required for VCM oxidation is estimated at 10,900 pounds assuming a very conservative stoichiometric ratio of 1:10 (VCM: permanganate). The exact permanganate requirement for VCM oxidation is dependent on the ability of permanganate to distribute itself throughout the VCM subplume and the presence of other oxidizable constituents in groundwater. The actual volume would be determined during the first stage testing.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk:

The magnitude of residual risk, as a result of the VCM subplume is incrementally decreased by Alternative 4B through reductions in the toxicity, mobility, and mass of VCM. The initial application of chemical oxidation would immediately, and significantly reduce the concentration of VCM in the MW-52 area thus reducing the

mass of VCM that is available to continue migrating to the south. The magnitude of residual risk is no less than for other alternatives because monitoring for VCM ensures that groundwater with elevated VCM is contained.

The potential for and magnitude of risk because of the metals present in the potassium permanganate will be evaluated using the results of the proposed OU-1 soil column tests.

Adequacy and Reliability of Remedy:

Alternative 4B is expected to effectively treat the groundwater with elevated VCM presence to acceptable VCM aquifer concentrations on the order of 40 µg/L. There would be limited short-term adverse effects to the environment as there would be no extraction and recharge of groundwater from/to the aquifer. There would be no adverse effect on the reliability of the Northrop IRM system because the VCM concentrations and mass from the area of well MW-52 would be significantly reduced. Therefore, Alternative 4B would be an adequate and permanent solution.

The results presented in the report entitled "Groundwater Laboratory Treatability Study Report" dated July 1999, and the documents in Appendix D demonstrate that VCM can be chemically oxidized. If this technology is selected as the remedy, predesign activities would need to be performed to determine the matrix oxidant demand and the delivery systems for the oxidant to insure adequate dispersion and mixing within the impacted groundwater regime.

Reduction of Toxicity, Mobility, and Volume

Alternative 4B would reduce the toxicity and mass of VCM using in situ chemical oxidation and natural attenuative processes. Groundwater would be treated until an average VCM concentration of approximately 40 µg/L was achieved. The mass of the VCM within the regional VOC plume would be reduced as would the other VOCs and TICs (if any). The in situ method would remove a sufficient mass of VCM that supplemental treatment of the GP-1 air discharge is not required. Any residual VCM that would not be treated by the in situ methodology would still be captured and treated by the Northrop IRM.

injection wells. Further consideration of trace metals in potassium permanganate will also have to be addressed to alleviate concerns present within the NYSDEC.

Potassium permanganate is commercially available and an appropriate solution concentration can be prepared and injected into groundwater. Injection permits would need to be obtained.

Permits would be required for the drilling of injection wells. These permits should be obtainable.

Availability of Service and Materials:

All the services, materials and equipment required for this treatment alternative are available from several subcontractors and suppliers.

Cost

The estimated capital cost is approximately \$1,566,000. The estimated O&M costs are approximately \$297,000 per year for chemical oxidation. The present worth costs, using a discount factor of 5 percent, over periods of 3, 5, and 10 years are shown below.

The possible requirement to use enhanced aerobic bioremediation for 2 years, coupled with the 3, 5, and 10-year periods of Alternative 4B is also shown. The 5-year time period represents the time frame most likely for this alternative.

| Operating Period (Years) | Chemical Oxidation Present Worth |
|--------------------------------|--|
| 3 | \$2,374,000 |
| 5 | \$2,850,000 |
| 10 | \$3,856,000 |

Chemical Oxidation and Enhanced Aerobic BioRemediation

| | |
|-------|-------------|
| 5 (1) | \$2,786,000 |
| 7(2) | \$3,225,000 |
| 12(3) | \$4,150,000 |

Notes:

- (1) 3 years chemical oxidation plus 2 supplemental years enhanced bioremediation.
- (2) 5 years chemical oxidation plus 2 supplemental years enhanced bioremediation.
- (3) 10 years chemical oxidation plus 2 supplemental years enhanced bioremediation.

For the most likely operating period of 5 years, the present worth cost ranges from \$2,850,000 (without supplemental 2 years of enhanced bioremediation) to \$3,225,000 (including supplemental 2 years of enhanced bioremediation). The above values do not include the minor Northrop IRM O&M contribution.

The reliance of Alternative 4B on the Northrop IRM for the treatment of residual chemicals in the groundwater from the VCM subplume will result in a minor contribution needing to be made toward the \$56,000,000 cost of the Northrop IRM.

5.2.4.3 ALTERNATIVE 4C: IN SITU TREATMENT OF VCM SUBPLUME BY BIOSPARGING

Alternative 4C would consist of treatment of the VCM subplume using in situ biosparging. The components of Alternative 4C include: continued operation of the Northrop IRM system to address the on-site regional VOC plume and in situ treatment of the VCM subplume using biosparging. If deemed necessary or desirable, the biosparging remedy could be enhanced by including aerobic bioremediation as a polishing step as discussed in Alternative 4A.

Overall Protection of Human Health and the Environment

Alternative 4C, provides additional protection to human health by minimizing the migration of VCM from the area around MW-52. Alternative 4C would also be protective of human health because groundwater monitoring would be employed to assess the migration of the regional VOC plume. Prohibition of private well placement would protect the health of current and future potential users. The other aspects relevant to this criteria are discussed under long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Chemical-specific ARARs:

Alternative 4C would reduce the concentrations of VCM in the aquifer near MW-52. The VCM subplume in the MW-52 area would be remediated with the intent of achieving average VCM concentrations of approximately 40 µg/L to ensure that supplemental VCM treatment of the air discharge at GP-1 of the Northrop IRM is not required. Biosparging would be performed to significantly decrease the VCM concentrations in the center of the subplume. This process would decrease VCM concentrations to 40 µg/L.

Action-Specific ARARs:

This treatment alternative would require the injection of air or oxygen into the affected groundwater for a period of approximately 3 years. Although the treatment is expected to eliminate a significant percentage of the VCM, the treatment period could be extended depending on the results. The exact air/oxygen requirement for VCM concentration reductions is dependent on the presence of other constituents in groundwater, and would be determined during the first stage testing.

In the event that enhanced aerobic bioremediation is also deemed necessary and/or desirable, it may be necessary to inject organic and/or inorganic nutrients into the aquifer to enhance microbial activities. The exact additives required to enhance VCM biodegradation would also be determined during the first stage testing. The injection of air/oxygen and nutrient additives into groundwater for full-scale treatment would need to be reviewed and approved in advance by the regulatory authorities.

Long-term Effectiveness and Permanence

Magnitude of Residual Risk:

The magnitude of residual risk, as a result of the VCM subplume is incrementally decreased by Alternative 4C through reductions in the toxicity, mobility, and mass of VCM. The initial biosparging would significantly reduce the concentration of VCM and other VOCs (except PCE and to a lesser degree TCE) in the MW-52 area and other treatment zones, reducing the mass of elevated VCM that is still available for migration to the south. The magnitude of residual risk is no less than for other alternatives because monitoring for VCM ensures that groundwater with elevated VCM is contained.

The results of the testing proposed in the June 11, 1999 submittal will be used to determine the air/oxygen injection rates to prevent the discharges of VCM through the vadose zone to the atmosphere at concentrations which would exceed Air Guide 1 criteria in either the breathing zone or subsurface enclosures (e.g., basements) as appropriate.

Adequacy and Reliability of Remedy:

Alternative 4C is expected to be adequate to treat the groundwater with elevated VCM presence. The introduction of air/oxygen into the groundwater is expected to enhance VCM biodegradation rates to achieve acceptable VCM aquifer concentrations. There would be limited short-term adverse effects to the environment as there would be no extraction and recharge of groundwater from/to the aquifer. There would be no adverse effect on the reliability of the Northrop IRM system because the VCM from the area of well MW-52 would be significantly reduced. Therefore, Alternative 4C would be an adequate and permanent solution.

Reduction of Toxicity, Mobility, and Volume

Alternative 4C would reduce the toxicity and mass of VCM and other VOCs (except PCE) using in situ biosparging processes. Groundwater would be treated until an average VCM concentration of approximately 40 µg/L was achieved. The mass of the VCM within the regional VOC plume would be reduced as would other VOCs and TICs (if any) except PCE and to a lesser degree TCE. The in situ method would remove a sufficient mass of the VCM that supplemental treatment of the GP-1 air discharge is not required. Any residual VCM that would not be treated by the in situ methodology would still be captured and treated by the Northrop IRM.

Short-term Effectiveness

Risks to Workers and Community:

This alternative involves minimal invasive activities once the injection phase commences. Risks during installation of the air/oxygen delivery system(s) would be minimized using appropriate health and safety measures. Risks to operators of the system will similarly be minimized.

Environmental Impacts:

As discussed earlier, the affected areas are industrialized with no sensitive flora or fauna. Therefore, the potential for environmental impacts of the remediation is not significant.

Time Until Remedial Action Objectives are Achieved:

It is expected that the biosparging treatment would be required to be continued for approximately three years to reduce the potential toxicity of VCM to levels amenable to natural attenuation. If needed, enhanced aerobic bioremediation could be required for a period of approximately two years to accomplish the remedial action objectives for a total operating period of 5 years.

Increasing or decreasing the number of air/oxygen injection locations, and the rate of injection, will also affect the duration. Periodic injections (monthly, bimonthly, quarterly) are suitable for both biosparging and, if needed, nutrient processes.

This alternative is expected to achieve or be very close to achieving the RAOs by the time the remnants of the VCM subplume reach well GP-1 of the Northrop IRM. If further reduction in groundwater chemical concentrations are needed to achieve MCLs, such polishing would be performed by the Northrop IRM.

Implementability

The limiting factor of vertical distribution for Alternatives 4A and 4B is reduced in Alternative 4C because Alternative 4C utilizes gases as opposed to liquid additives. The injection system would deliver the air/oxygen as a gas at or below the vertical extent of the VCM subplume. The gas would then percolate upwards giving adequate vertical distribution. Impervious barriers (clay layers) would initially act as a barrier to the upward percolation of the air/oxygen. However, it is anticipated that as the air/oxygen column grows larger below the impervious barrier, it would also migrate laterally to areas where the barrier does not exist and then continue its upward percolation. Placement of some injection points above large impervious layers is likely to be necessary to provide effective air/oxygen injections of air/oxygen into the groundwater. Multi-level injection ports on the injection wells, could also be used to provide improved vertical distribution.

One concern with this alternative is the possibility of volatilizing VOCs into the air/oxygen as it is injected into the VCM subplume. To alleviate this concern

monitoring of VOC levels present in the overburden can be conducted. It is anticipated that such air stripping will not be problematic because of the minimal volume and periodic injections of air/oxygen into the groundwater. Periodic, low volume injections will allow most, if not all of the injected air/oxygen to be dissolved into the groundwater prior to reaching the vadose zone. Any small residual amounts of air/oxygen reaching the vadose zone will still need to migrate through approximately 50 feet of unsaturated soil before reaching the atmosphere. Any chemicals migrating through the vadose zone will continue to undergo further reductions in concentration by natural attenuative processes. Thus, it is expected that injected gas reaching the shallow soil/atmosphere, if any, would not contain VOCs at concentrations of concern.

Biosparging technologies are commercially available. Similarly, several nutrient sources suitable for the enhancement of VCM biodegradation are commercially available and may be used if needed. Injection permits would need to be obtained.

Permits would be required for the drilling of injection wells. These permits should be obtainable.

Availability of Service and Materials:

All the services, materials and equipment required for this treatment alternative are available from several subcontractors and suppliers.

Cost

The estimated capital cost is approximately \$1,260,000. The estimated O&M costs are approximately \$319,000 for biosparging per year. The present worth costs, using a discount factor of 5 percent over periods of 3, 5, and 10 years are shown below. Also shown, are the present worth costs to account for the possible requirement of using enhanced aerobic bioremediation for 2 years, associated with the 3, 5, and 10 year periods. The 3-year time period represents the most likely time frame for this alternative.

| Operating Period (Years) | Biosparging Present Worth |
|--------------------------------|---------------------------------|
| 3 | \$2,129,000 |
| 5 | \$2,641,000 |
| 10 | \$3,723,000 |

Biosparging and Enhanced Aerobic Bioremediation

| Operating Period (Years) | Present Worth |
|--------------------------------|------------------|
| 5 ⁽¹⁾ | \$2,542,000 |
| 7 ⁽²⁾ | \$3,016,000 |
| 12 ⁽³⁾ | \$4,016,000 |

Notes:

- (1) 3 years biosparging plus 2 supplemental years enhanced bioremediation.
- (2) 5 years biosparging plus 2 supplemental years enhanced bioremediation.
- (3) 10 years biosparging plus 2 supplemental years enhanced bioremediation.

For the most likely operating period of 3 years, the present worth cost ranges from \$2,129,000 (without supplemental 2 years of enhanced bioremediation) to \$2,542,000 (including 2 years of enhanced bioremediation). The above values do not include the minor Northrop IRM O&M contribution.

The reliance of Alternative 4C on the Northrop IRM for the treatment of residual chemicals on the groundwater from the VCM subplume will result in a minor contribution needing to be made toward the \$56,000,000 cost of the Northrop IRM.

6.0 COMPARATIVE ANALYSIS

This section presents a comparative analysis of the alternatives that were analyzed in detail in Section 5.0. The comparison will be used to evaluate the advantages and disadvantages of the alternatives based on the same seven criteria that were used for the detailed analysis.

The seven alternatives are as follows:

- Alternative 1: - No Further Action - Northrop IRM (No VCM Treatment);
- Alternative 2: - Enhanced Northrop IRM (Supplemental VCM Treatment If Necessary);
- Alternative 3A: - VCM Subplume Containment, Treatment, and Discharge for VCM Mass Reduction;
- Alternative 3B: - VCM Subplume Containment, Treatment, and Discharge to Achieve Groundwater ARARs; and
- Alternative 4A: - In Situ Treatment of VCM Subplume by Enhanced Aerobic Bioremediation for VCM Mass Reduction.
- Alternative 4B: - In Situ Treatment of VCM Subplume by Chemical Oxidation for VCM Mass Reduction.
- Alternative 4C: - In Situ Treatment of VCM Subplume by Biosparging for VCM Mass Reduction.

6.1 OVERALL PROTECTION OF HUMAN HEALTH AND ENVIRONMENT

All alternatives provide capture of the VCM contaminated groundwater and thus protect human health and the environment in the following decreasing order (i.e., most protective to least protective):

1. Alternative 3B
2. Alternative 3A
Alternative 4A
Alternative 4B
Alternative 4C
3. Alternative 2
4. Alternative 1

Alternative 3B is most protective because VCM concentrations are reduced to MCLs in the MW-52 area, whereas Alternatives 3A, 4A, 4B, and 4C remove VCM mass from the MW-52 area to concentrations such that supplemental VCM treatment of air discharge at GP-1 is not required for the Northrop IRM. Alternative 2 allows VCM to remain in the MW-52 area and migrate to the Northrop IRM where supplemental VCM treatment of air discharges at GP-1 will likely be required. Alternative 1 is least protective because although containment and groundwater treatment for the VCM is provided by the Northrop IRM, no treatment of the IRM air discharges for VCM is provided.

6.2 COMPLIANCE WITH ARARs AND TBCs

All alternatives, except for Alternative 1, comply with chemical-specific ARARs, which consist primarily of federal and state MCLs for groundwater and water supply and air discharge criteria. Alternative 1 does not comply because no treatment of the IRM air discharges for VCM is provided. All alternatives, except for Alternative 1, comply with action specific ARARs which include regulations for discharge of air and water streams, as well as off-site transportation and disposal of hazardous wastes (solvents).

6.3 LONG-TERM EFFECTIVENESS AND PERMANENCE

All alternatives, except for air discharges for Alternative 1, should be effective in the long term, because at the end of the remediation, no groundwater with elevated VCM concentrations will remain to the extent that further treatment is required to protect human health and the environment.

6.4 REDUCTION OF TOXICITY, MOBILITY, AND VOLUME

All alternatives offer a reduction in toxicity, via VCM destruction, in the following decreasing order (greatest reduction to least reduction):

1. Alternative 3B
2. Alternative 3A
Alternative 4A
Alternative 4B
Alternative 4C
3. Alternative 2
4. Alternative 1

Alternative 3B is ranked first because it reduces VCM subplume concentrations in the MW-52 area to achieve the MCL for VCM more quickly. Alternatives 3A, 4A, 4B, and 4C all reduce the VCM subplume mass so that supplemental treatment at the Northrop IRM is not required. Ultimately, under each of the alternatives all of the VCM subplume will either be captured through groundwater extraction and treated or addressed through in situ treatment (except for the off-gas for Alternative 1).

6.5 SHORT-TERM EFFECTIVENESS

Although all of the alternatives are expected to be effective in the short term, the potential for worker and community exposure to chemicals varies between the alternatives. The potential risk of a release of chemicals or the potential hazards of operating the treatment system is proportional to the volume of water treated, the type and concentration of chemicals in the water, and the type of treatment used.

The potential exposure of workers and the community to VCM from industrial well treatment system off-gases, if constructed, would be controlled.

The most representative time period for which each Alternative is required to operate varies as follows:

| <i>±3 Years</i> | <i>±5 Years</i> | <i>±10 Years</i> | <i>±30 Years</i> | <i>>50 Years</i> |
|---------------------|----------------------------------|------------------|------------------|--------------------------------|
| <u>(very short)</u> | <u>(short)</u> | <u>(medium)</u> | <u>(long)</u> | <u>(very long)</u> |
| Alternative 4 C | Alternative 3A Alternative 4B | Alternative 4A | Alternative 3B | Alternative 2 Alternative 1 |

The above durations do not include the time necessary to fully reach the remedial action objectives which require all of the impacted groundwater to flow to the Northrop IRM (>50 years).

6.6 IMPLEMENTABILITY

Although all of the alternatives are expected to be implementable, the ease of installation and operation for the treatment plants vary based on the number of treatment units, the type of treatment, and location of the units.

Alternative 1 is the easiest to implement as the Northrop IRM is already operational.

Alternative 2 is the same as Alternative 1 except that additional sentinel monitoring for VCM would be performed and treatment of the off-gas from GP-1 for VCM would be implemented if needed.

Alternatives 3A and 3B would take longer to implement than Alternatives 1 and 2, because they would require the construction of groundwater extraction and treatment units and tie-ins to existing utilities.

Alternatives 4A, 4B, and 4C involve the in situ degradation/destruction of the VCM. Implementation requires installation of permanganate/nutrient/air/oxygen delivery systems. The Phase I Remediation would be required to be performed to confirm all of the design components. Alternatives 4A and 4B use liquids as the carrier of additives and these are more dependant on the hydraulic characteristics of the groundwater flow system to achieve additive distribution than Alternative 4C. Also, liquid distribution may be limited by clay layers within the aquifer. Alternative 4C uses air or oxygen as the additive. The gas has greater distribution potential including superior ability to migrate upward from the injection location and thereby has greater potential to impact

more of the impacted aquifer. Both liquid and gas delivery systems may require multiple injection points at various elevations to overcome vertical migration limiting factors (e.g., clay layers).

Permits or permit modifications would be required for the discharge of air and treated groundwater for each of the alternatives. These permits should be obtainable.

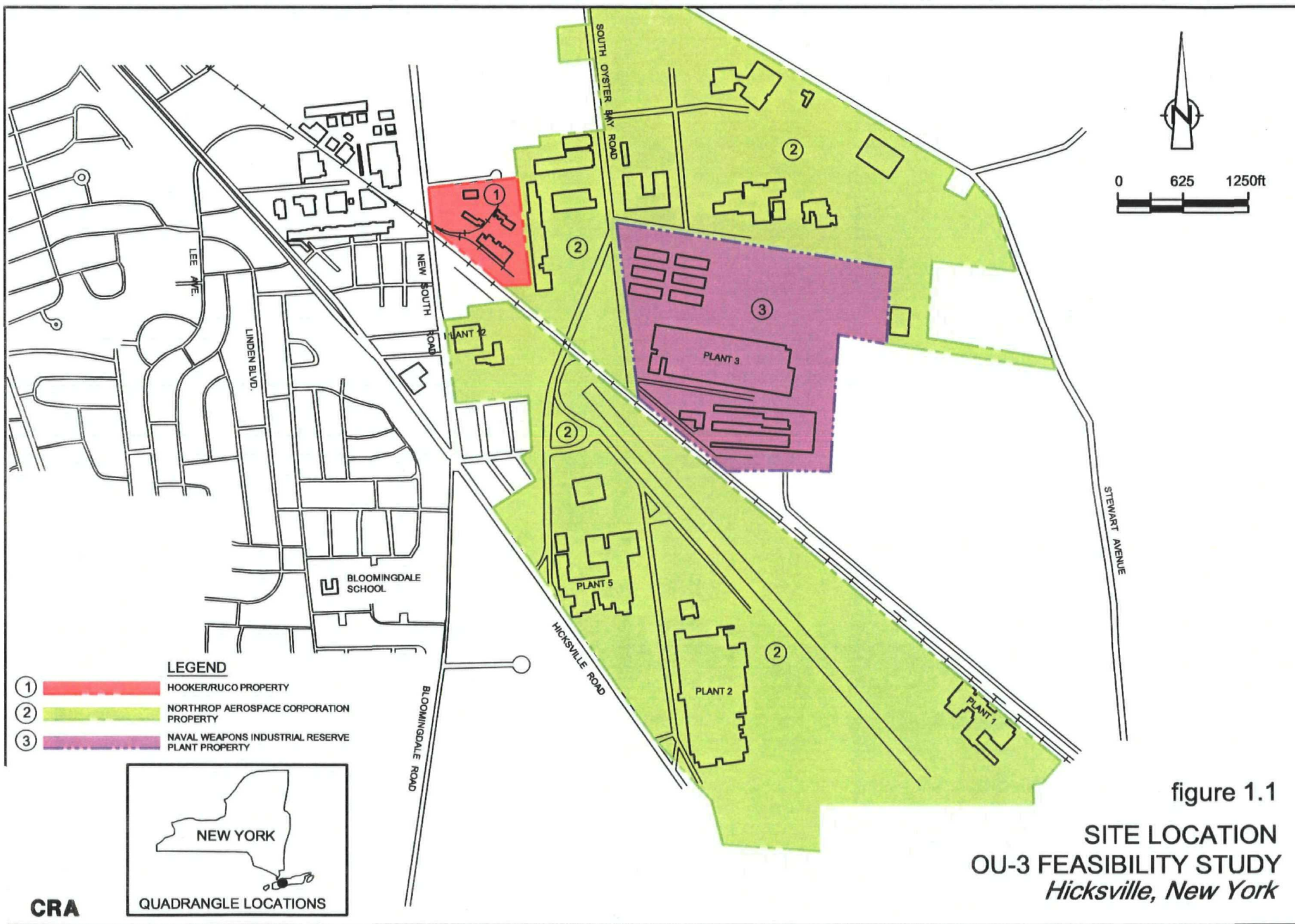
6.7 COST

The estimated capital and O&M costs for each of the alternatives for the most representative time period of operation is summarized. Details on these cost estimates and for the low and high operating periods are provided in Appendix B.

| <i>Alternative</i> | <i>Capital (\$)</i> | <i>Operation & Maintenance (\$/yr)</i> | <i>Most Likely Years of Operation</i> | <i>Present Worth (\$)</i> | <i>Requires Minor Contribution toward Northrop IRM⁽¹⁾</i> |
|--------------------|---------------------|--|---------------------------------------|---|--|
| 1 | 0 | 0 | 70 | 0 | Yes |
| 2 | 456,000 | 123,000 | 70 ⁽³⁾ | 330,000 | Yes |
| 3A | 3,474,000 | 643,000 to 691,000 | 5 | \$6,258,000 to \$6,465,000 | Yes |
| 3B | 4,195,000 | 679,000 to 727,000 | 30 | \$14,633,000 to \$15,370,000 | No |
| 4A | 1,566,000 | 257,000 | 10 | \$3,551,000 | Yes |
| 4B | 1,566,000 | 297,000 | 5 | \$2,850,000 to \$3,225,000 ⁽²⁾ | Yes |
| 4C | 1,260,000 | 319,000 | 3 | \$2,129,000 to \$2,542,000 ⁽²⁾ | Yes |

Notes:

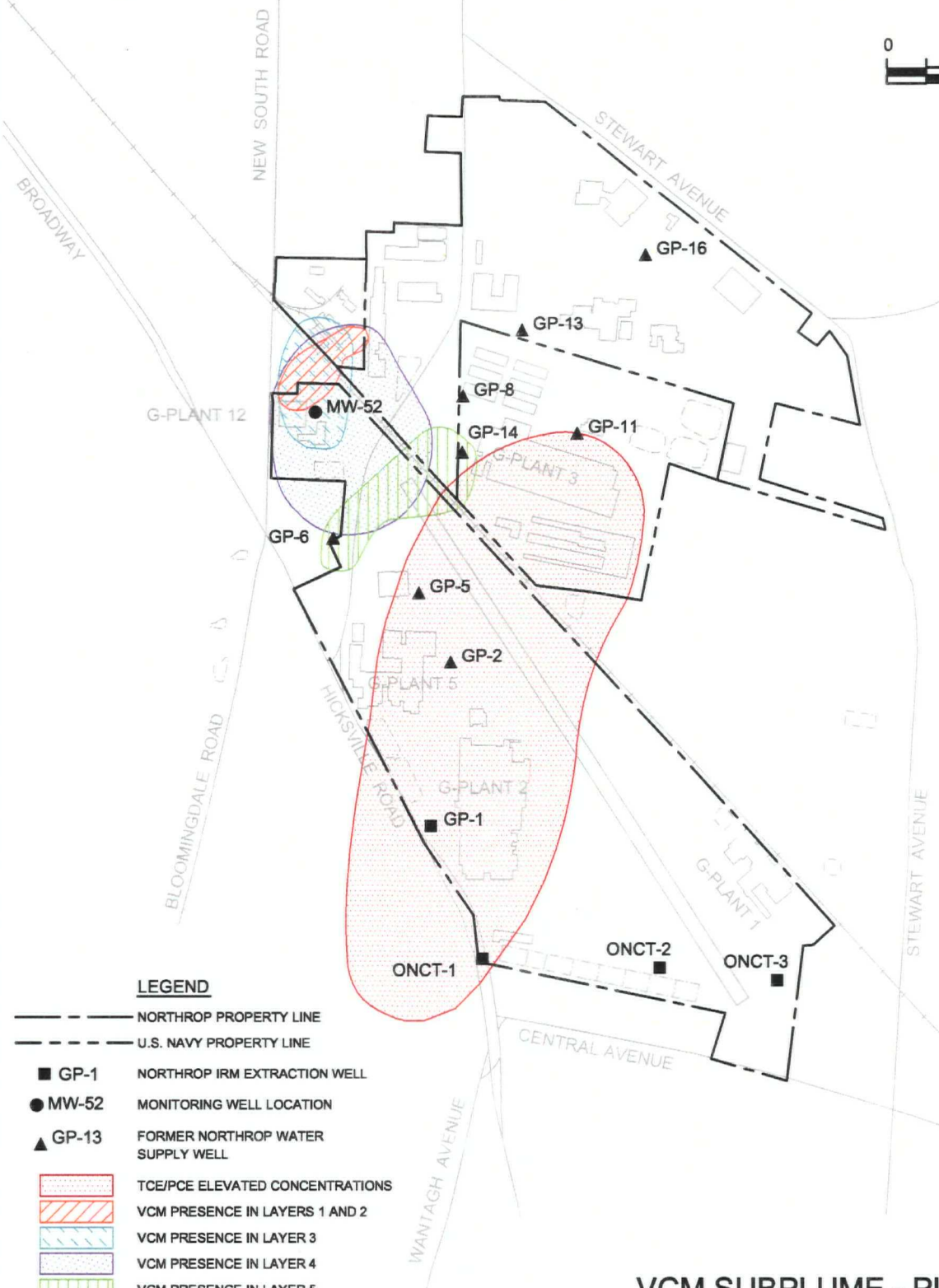
- (1) A minor contribution toward the Northrop IRM cost of \$56,000,000 must be added. However, the amount of the contribution is indeterminate at this time.
- (2) Range is provided to account for the possible requirement to use enhanced aerobic bioremediation for an additional two years.
- (3) Operation would start in 40 years.



CRA

06883-00(018)GN-WA005 JUL 25/2000

400166



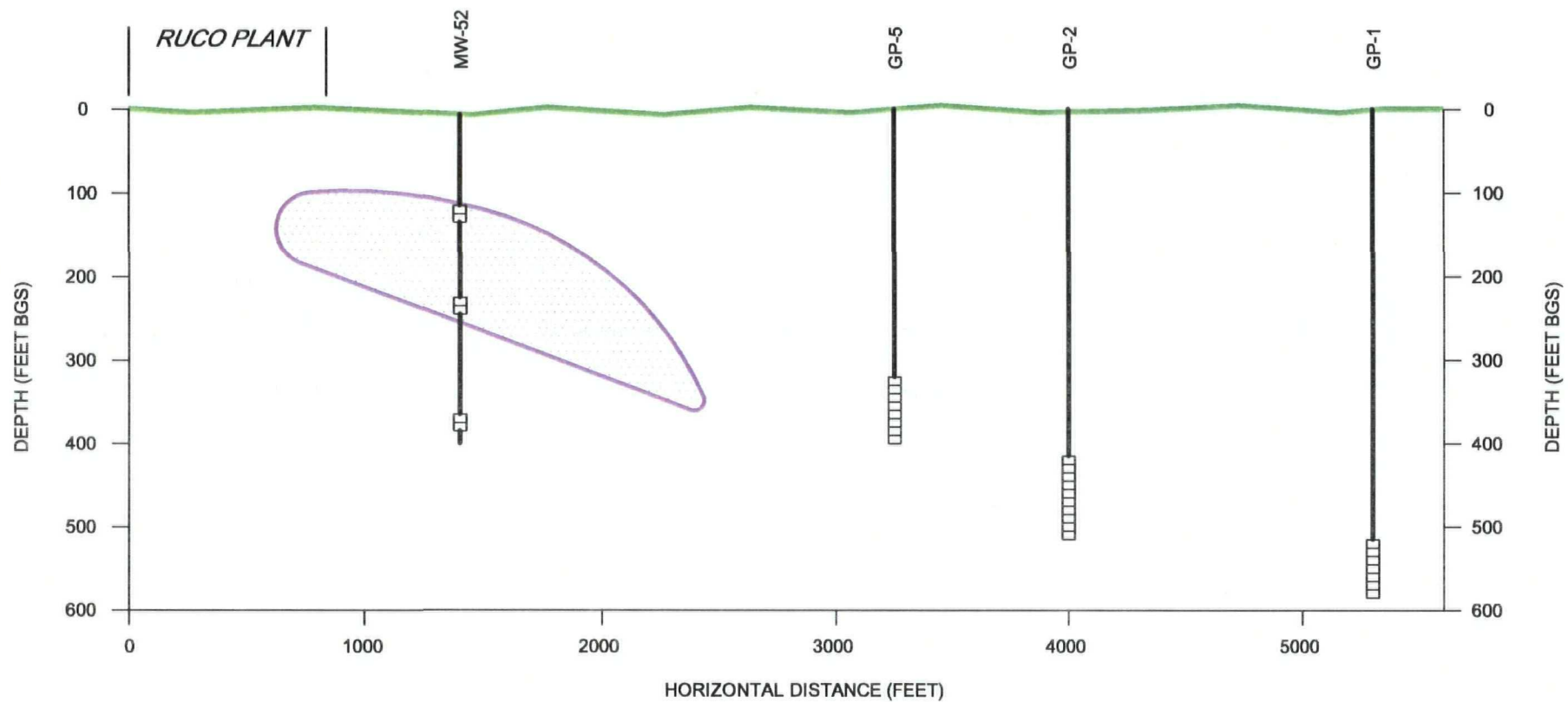
LEGEND

- NORTHROP PROPERTY LINE
- U.S. NAVY PROPERTY LINE
- GP-1 NORTHROP IRM EXTRACTION WELL
- MW-52 MONITORING WELL LOCATION
- ▲ GP-13 FORMER NORTHROP WATER SUPPLY WELL
- [Red hatched box] TCE/PCE ELEVATED CONCENTRATIONS
- [Orange hatched box] VCM PRESENCE IN LAYERS 1 AND 2
- [Blue hatched box] VCM PRESENCE IN LAYER 3
- [Purple hatched box] VCM PRESENCE IN LAYER 4
- [Green hatched box] VCM PRESENCE IN LAYER 5

VCM PRESENCE BASED ON APRIL AND MAY 1996 GROUNDWATER ANALYTICAL RESULTS

CRA

figure 3.1
VCM SUBPLUME - PLAN VIEW
OU-3 FEASIBILITY STUDY
Hicksville, New York



LEGEND



CORRESPONDS TO A
CONCENTRATION OF 10 ug/L

VCM PRESENCE BASED ON APRIL AND MAY 1996
GROUNDWATER ANALYTICAL RESULTS

figure 3.2

VCM SUBPLUME - CONCEPTUAL CROSS-SECTION
OU-3 FEASIBILITY STUDY
Hicksville, New York

CRA



0 750 1500ft

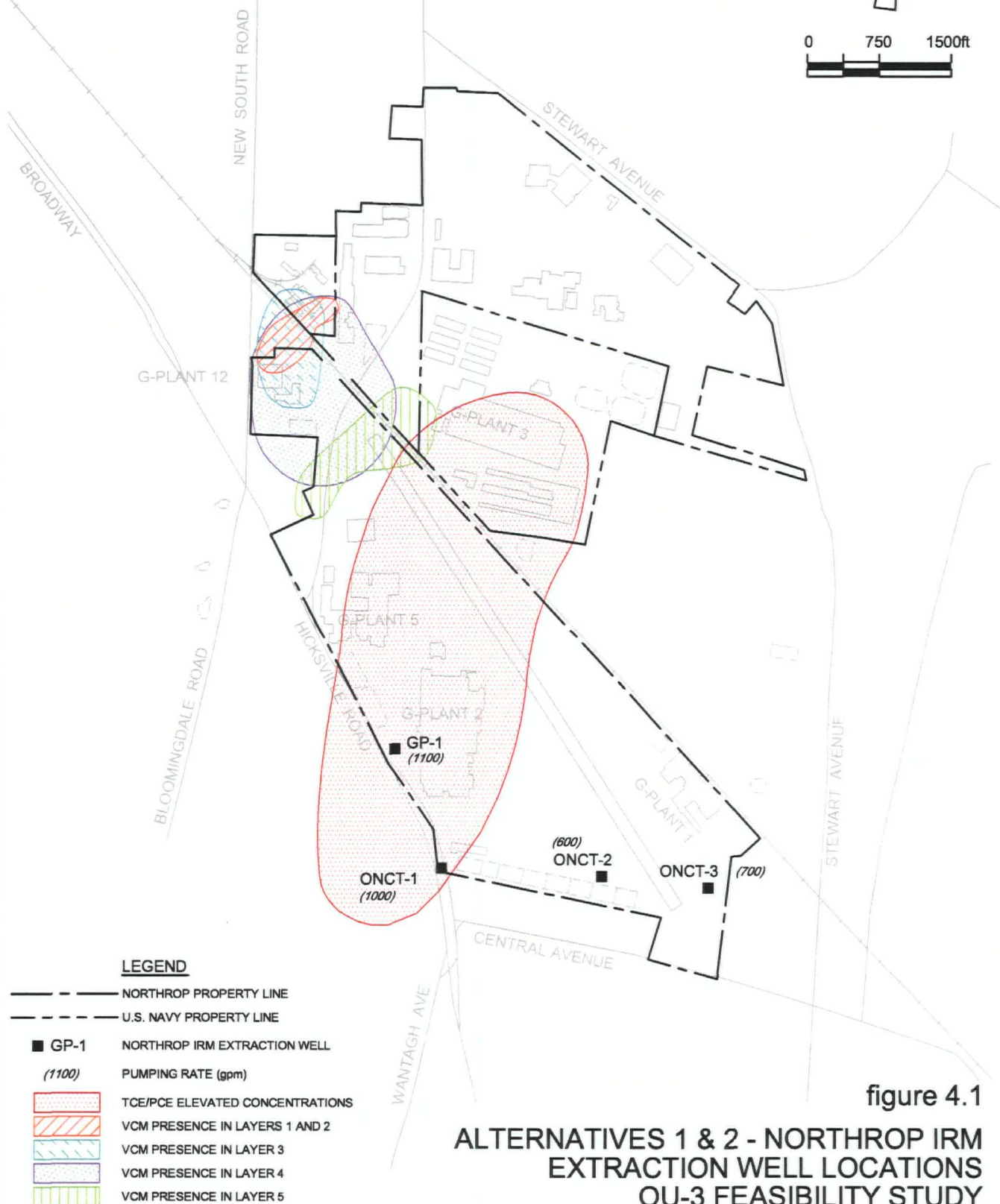


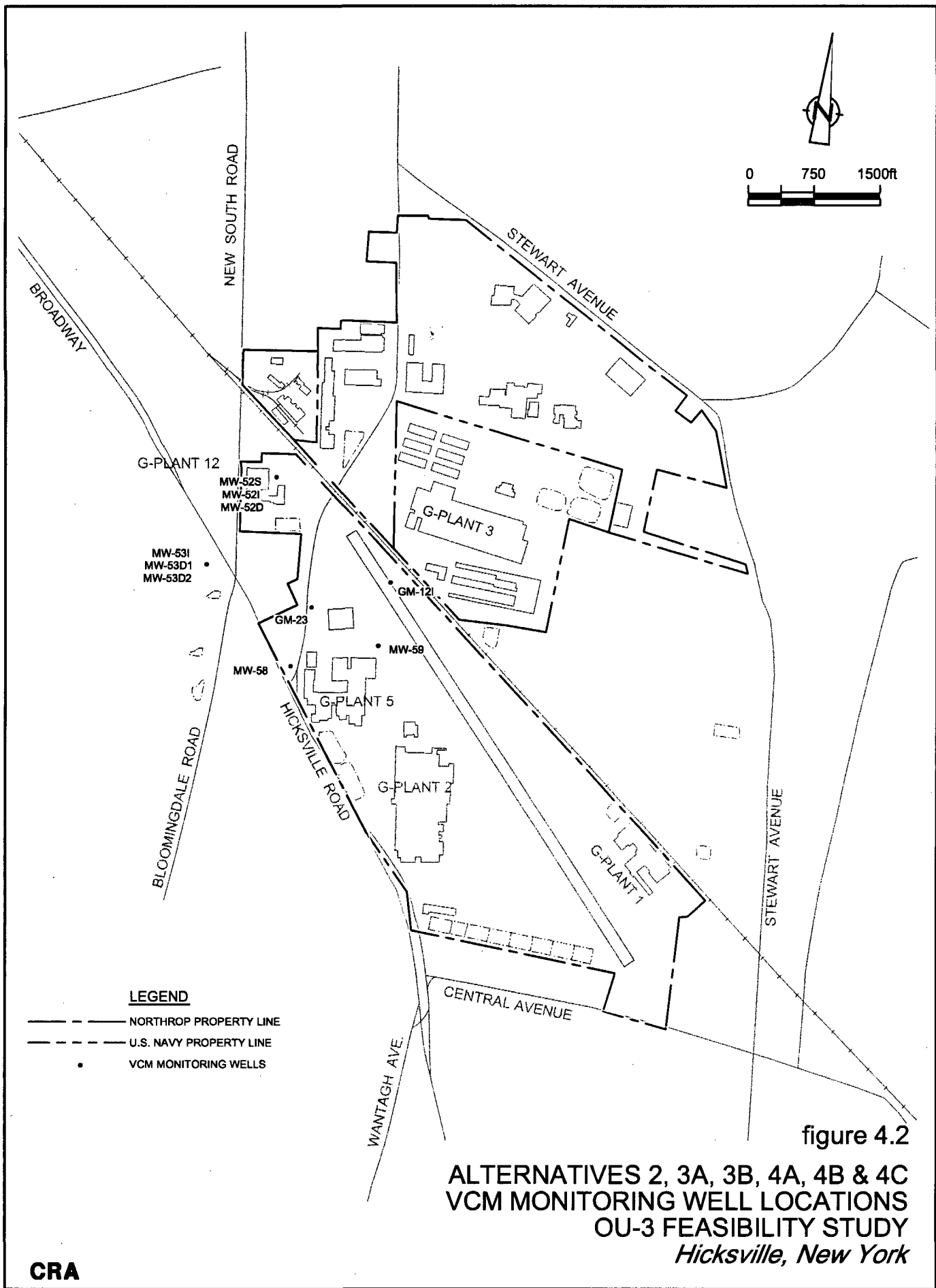
figure 4.1

**ALTERNATIVES 1 & 2 - NORTHROP IRM
EXTRACTION WELL LOCATIONS
OU-3 FEASIBILITY STUDY
Hicksville, New York**

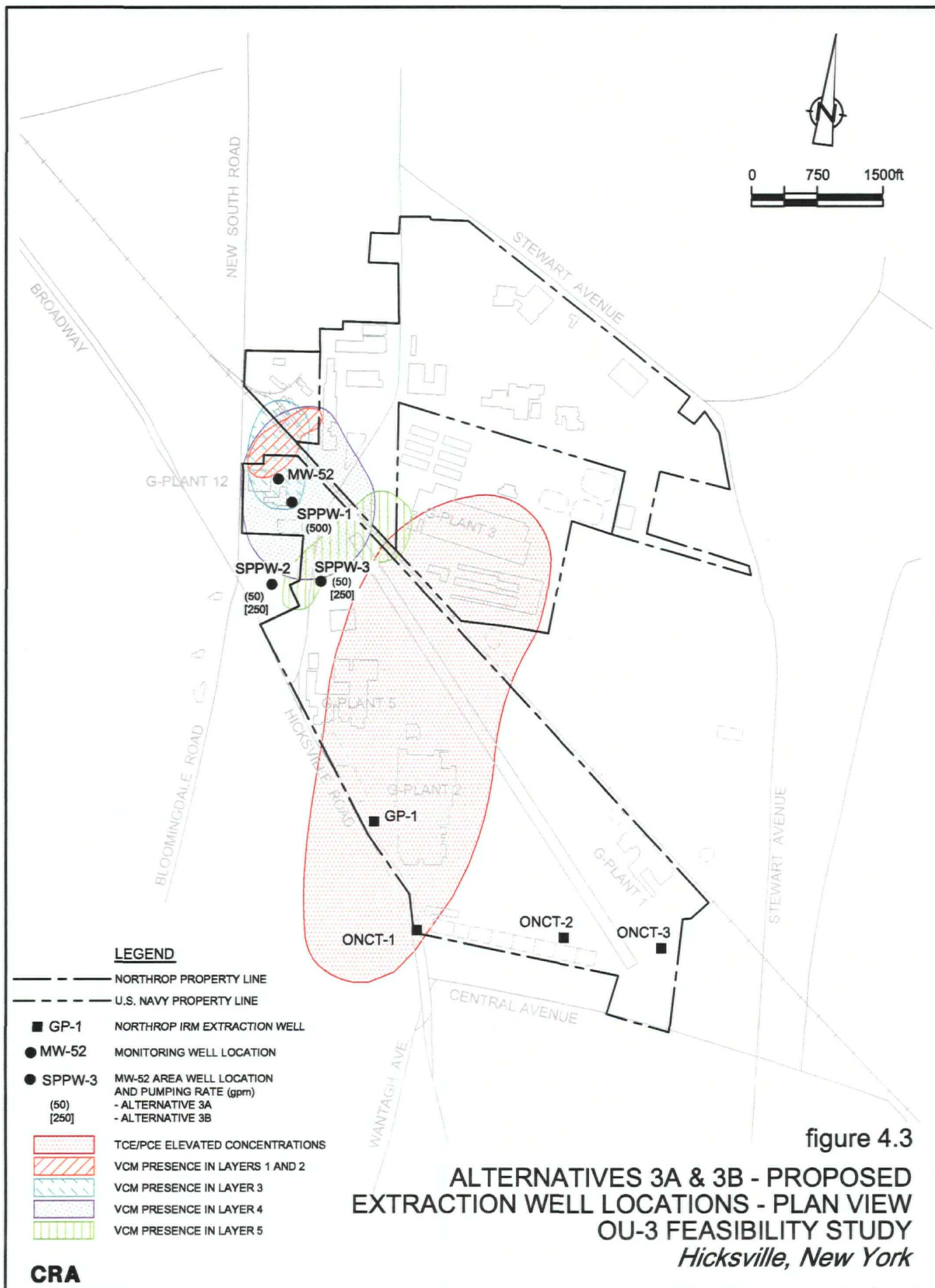
CRA

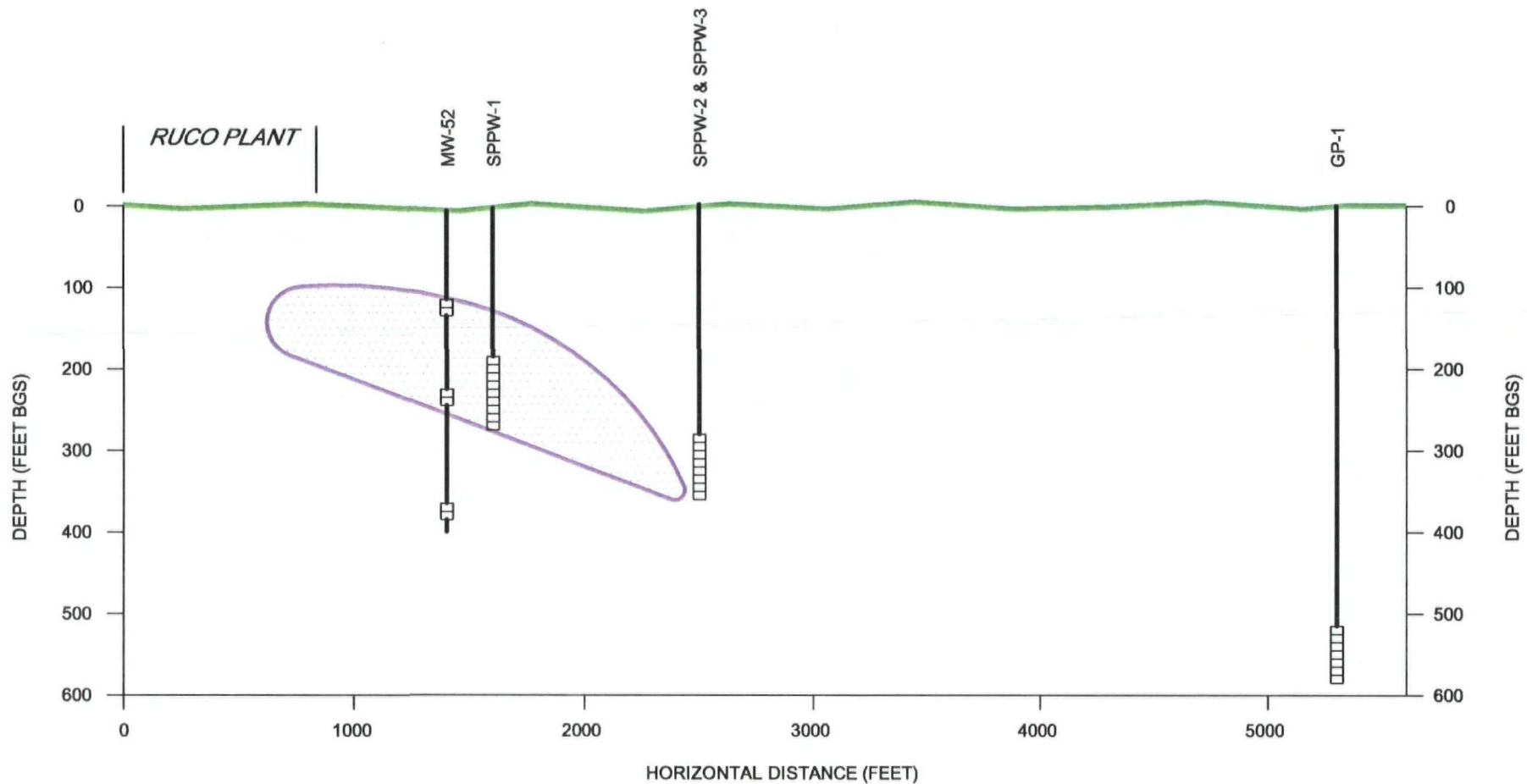
06883-00(018)GN-WA008 JUL 25/2000

400169



CRA





LEGEND

CORRESPONDS TO A
CONCENTRATION OF 10 ug/L

figure 4.4

ALTERNATIVE 3A/3B - PROPOSED EXTRACTION
WELL LOCATIONS - CROSS-SECTION
OU-3 FEASIBILITY STUDY
Hicksville, New York



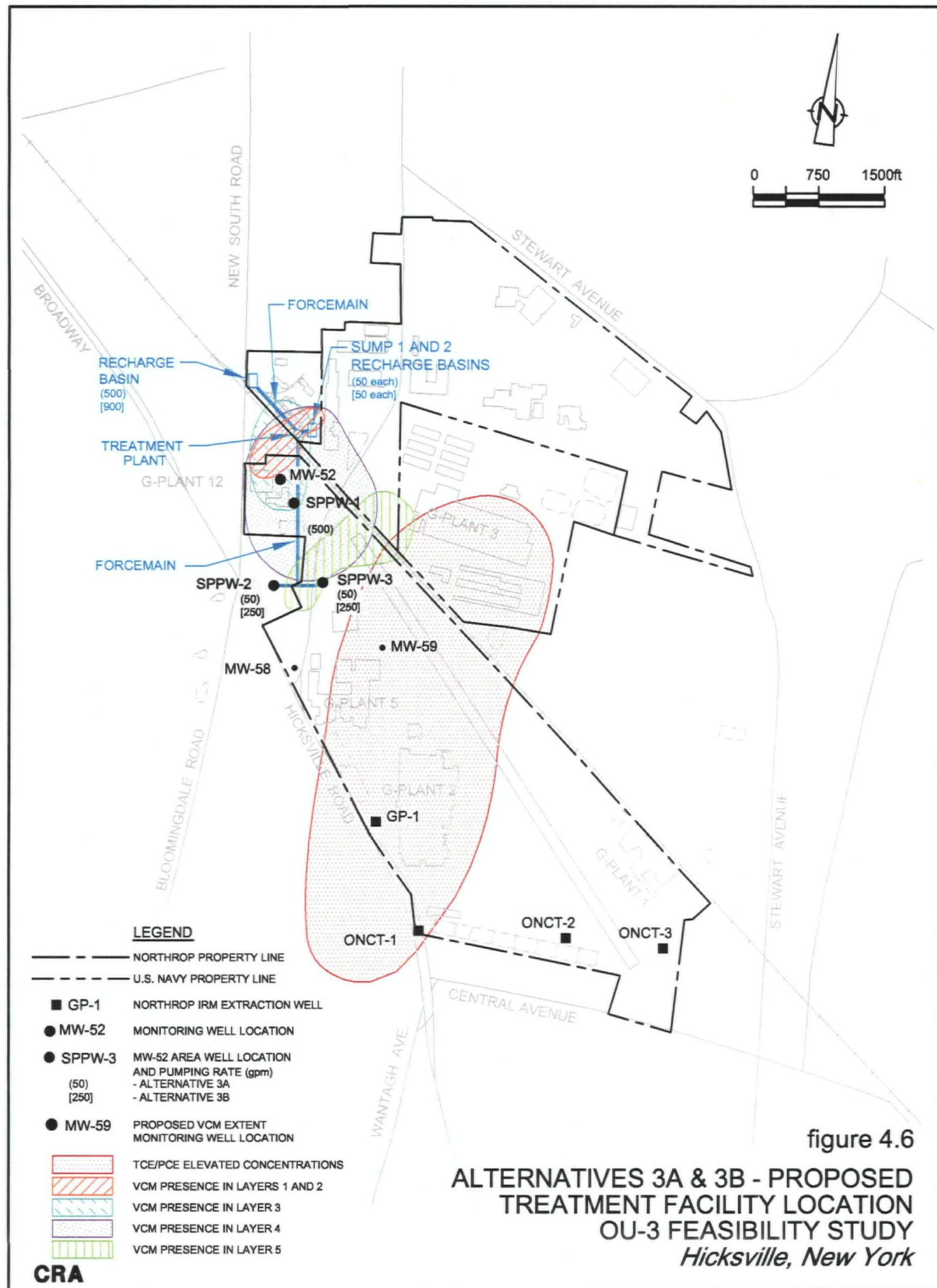
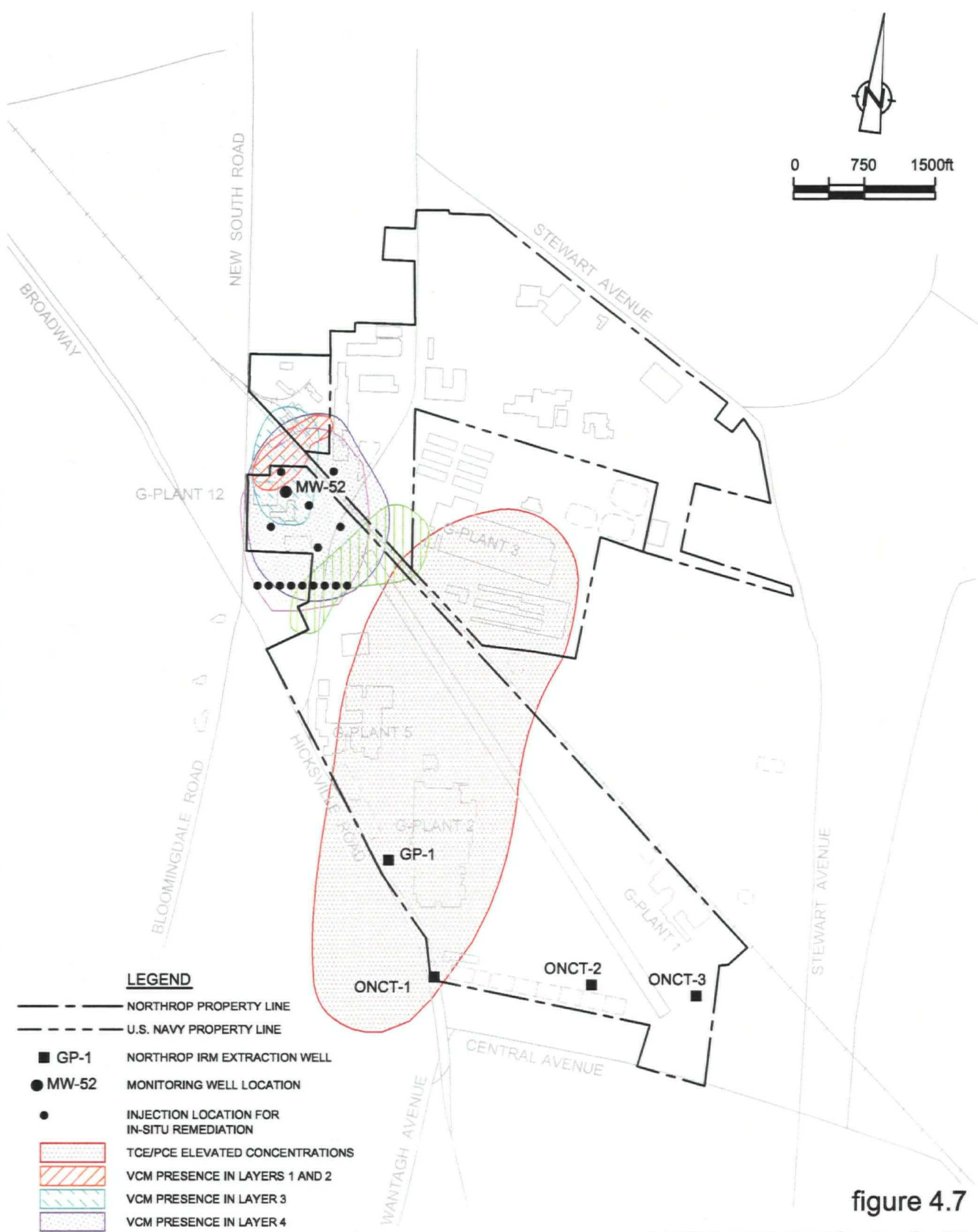


figure 4.6

**ALTERNATIVES 3A & 3B - PROPOSED
TREATMENT FACILITY LOCATION
OU-3 FEASIBILITY STUDY
Hicksville, New York**



- LEGEND**
- NORTHROP PROPERTY LINE
 - U.S. NAVY PROPERTY LINE
 - GP-1 NORTHROP IRM EXTRACTION WELL
 - MW-52 MONITORING WELL LOCATION
 - INJECTION LOCATION FOR IN-SITU REMEDIATION
 - [Red hatched box] TCE/PCE ELEVATED CONCENTRATIONS
 - [Blue hatched box] VCM PRESENCE IN LAYERS 1 AND 2
 - [Green hatched box] VCM PRESENCE IN LAYER 3
 - [Purple hatched box] VCM PRESENCE IN LAYER 4
 - [Yellow hatched box] VCM PRESENCE IN LAYER 5

figure 4.7
ALTERNATIVES 4A & 4B
OU-3 FEASIBILITY STUDY
Hicksville, New York

CRA



0 750 1500ft

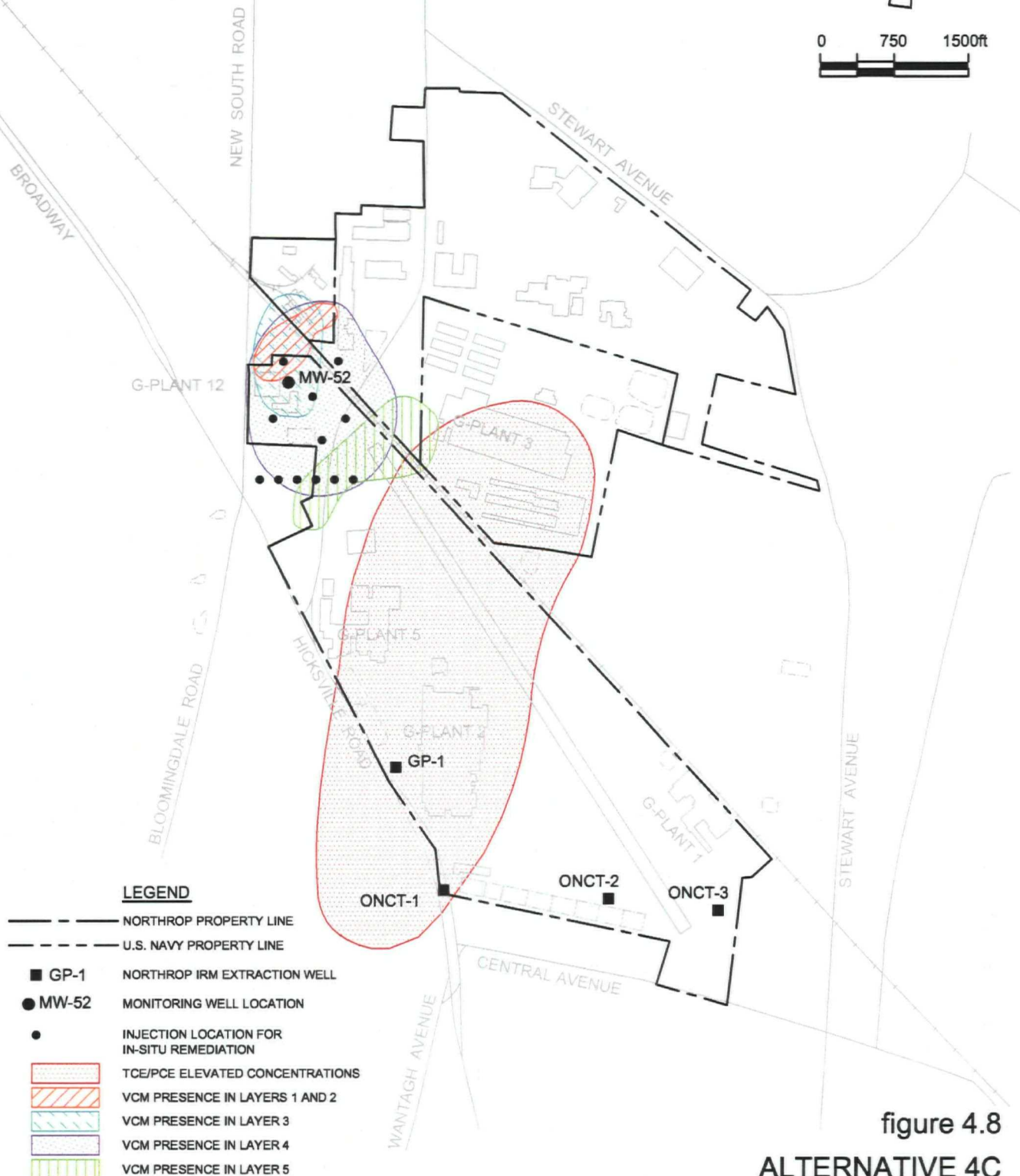


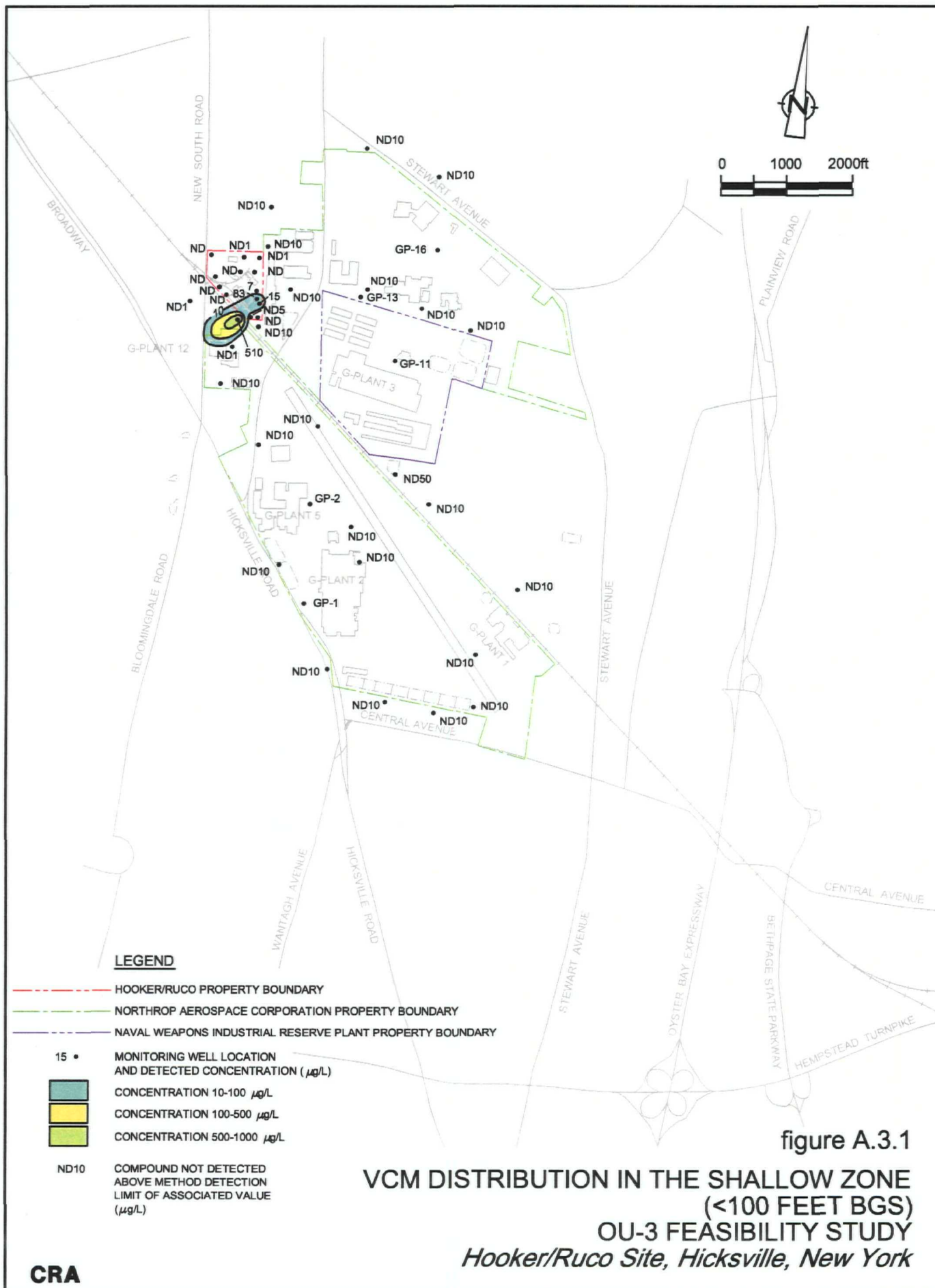
figure 4.8

ALTERNATIVE 4C
OU-3 FEASIBILITY STUDY
Hicksville, New York

CRA

06883-00(018)GN-WA016 JUL 25/2000

400176



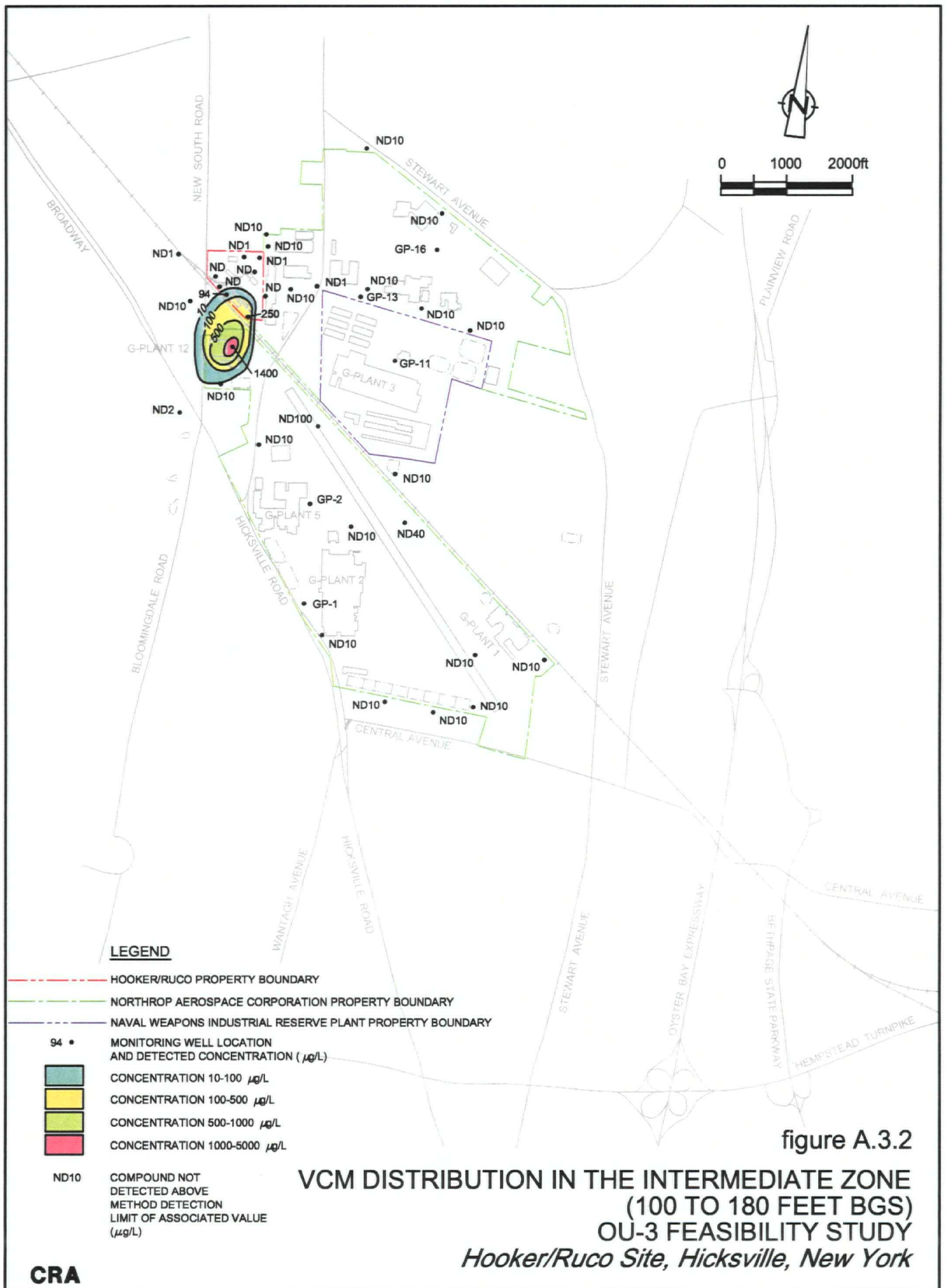
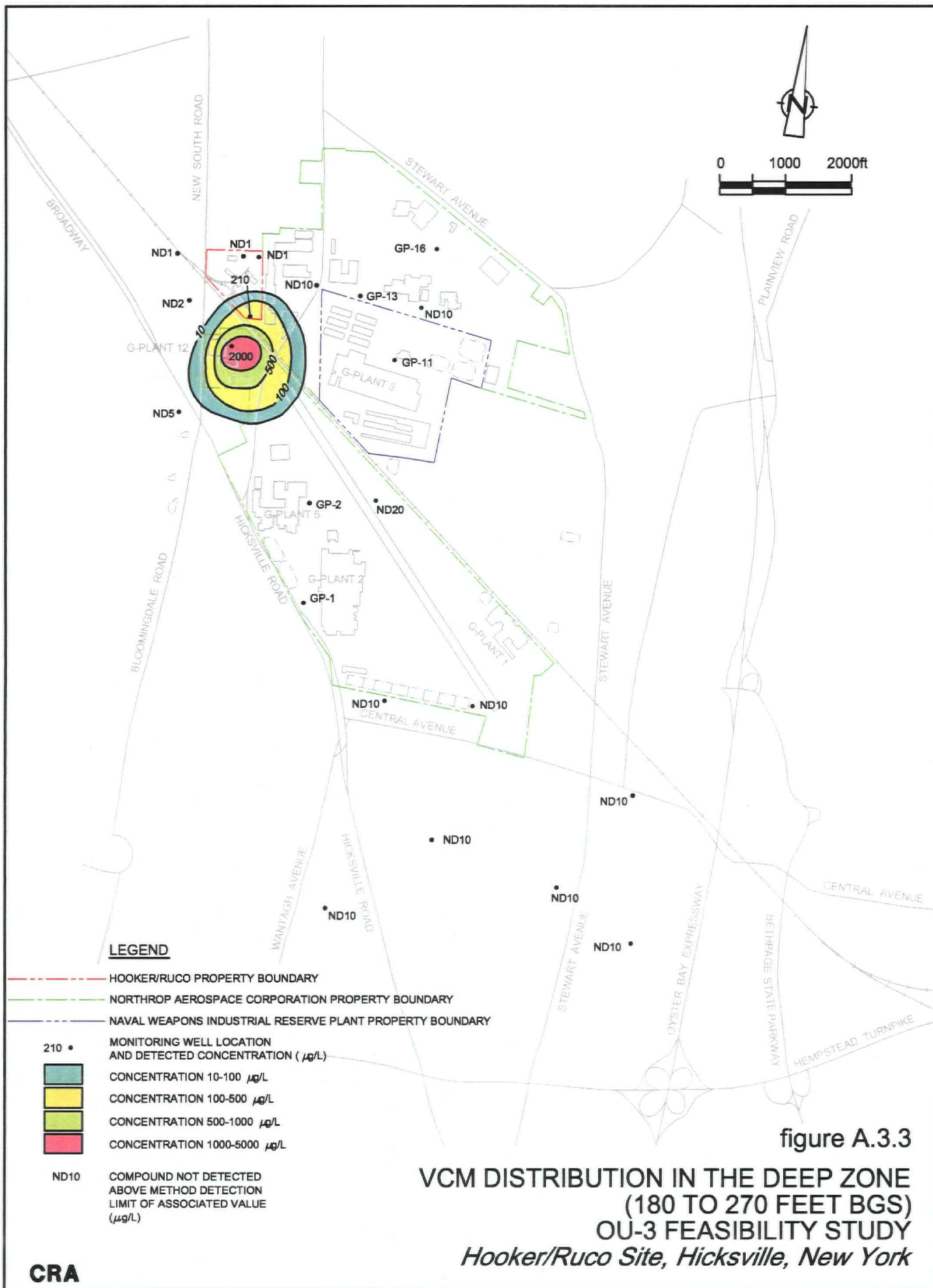


figure A.3.2



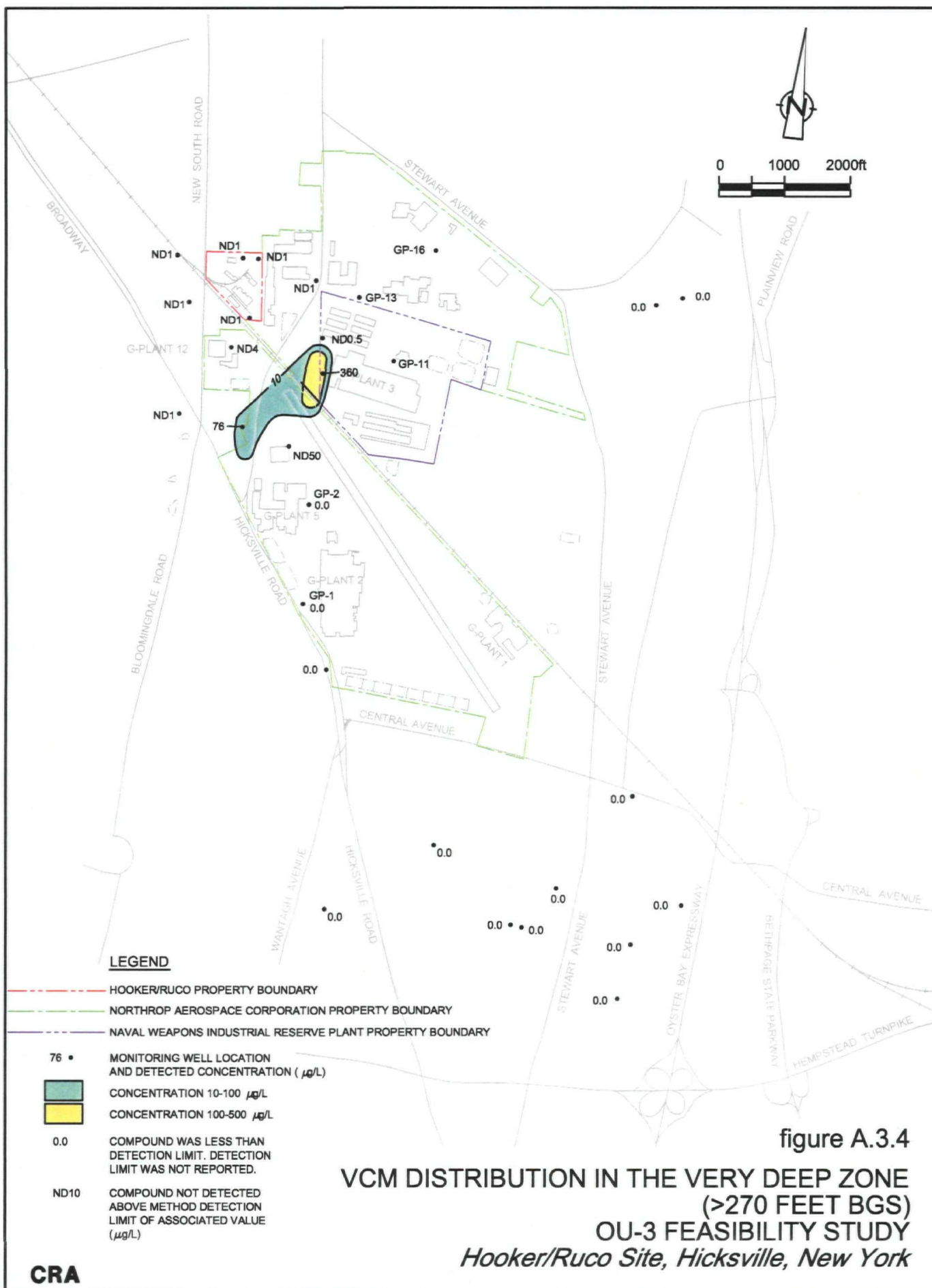


TABLE 2.1

**SUMMARY OF REASONABLE MAXIMUM EXPOSURE(1)
RISK BY GROUNDWATER
HOOKER/RUCO SITE, HICKSVILLE, NEW YORK**

| <i>Receptor</i> | <i>Exposure Pathway</i> | <i>Carcinogenic Risk</i> | <i>Major Contributors</i> | <i>Percent Contribution by VCM</i> | <i>Noncarcinogenic Risk</i> | <i>Major Contributors</i> |
|-----------------|-----------------------------|------------------------------|-------------------------------|--|---------------------------------|---|
| Child Resident | Inhalation | 1.09E-04 | VCM | 98 | 0.12 | Carbon Disulfide, 4-Methyl-2-Pentanone |
| Adult Resident | Inhalation | 5.06E-04 | | 99 | 0.058 | |
| Child Resident | Ingestion | 8.84E-04 | VCM, Arsenic, | 69 | 10.2 | Antimony, Arsenic |
| Adult Resident | Ingestion | 2.21E-03 | Beryllium, PCE | 69 | 4.89 | |
| Child Resident | Dermal Contact | 1.34E-05 | VCM, Arsenic, | 66 | 0.12 | Antimony, Arsenic, PCE, Bis(2-ethylhexyl)phthalate |
| Adult Resident | Dermal Contact | 1.12E-04 | PCE | 65 | 0.20 | |

Note:

(1) 95% Upper Confidence Limit concentration for VCM = 68.5 µg/L.

400182

TABLE 3.1
FEDERAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
HOOKE/RUCO SITE
HICKSVILLE, NEW YORK

| <i>ARAR Citation</i> | <i>Rationale for Use</i> | <i>Type of Requirement</i> |
|--|--|--------------------------------------|
| <u>Contaminant-Specific</u> | | |
| Safe Drinking Water Act (42 USC 300) - Maximum Contaminant Levels (MCLs) 40 CFR 141.11-141.16 - Maximum Contaminant Level Goals (MCLGs) 40 CFR 141.50-141.51 | Applicable in developing remediation goals for the contaminated groundwater in accordance with SARA Section 121(d)(2)(A)(iii). Also considered as discharge criteria for alternatives including groundwater treatment. | Applicable |
| Reference Doses (RfDs), EPA Office of Research and Development | To be considered (TBC) requirement in the public health assessment. | TBC |
| Carcinogenic Potency Factors, EPA Environmental Criteria and Assessment Office; EPA Carcinogen Assessment Group | TBC requirement in the public health assessment. | TBC |
| Health Advisories, EPA Office of Drinking Water | TBC requirement in the public health assessment. | TBC |
| Clean Air Act (42 USC 7401) National Ambient Air Quality Standards (NAAQS) (40 CFR Part 50) | Site alternatives may result in emission of unacceptable levels of airborne particulates to the atmosphere. The primary (and secondary standard) for particulate matter, expressed as PM-10 is 150 [24-hour, annual arithmetic mean] and 50 [1-year, annual arithmetic mean]. Construction activities and VOC emissions from air stripping are of particular concern during remediation. | Potentially Applicable |
| Clean Air Act (42 USC 7401) National Emissions Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR Part 61) | Standards are possibly, but not likely, to be relevant and appropriate since these standards were developed for specific, significant sources. Particulates and VOCs are of primary concern. | Potentially Relevant and Appropriate |
| Air/Superfund National Technical Guidance Study Services | Emission factors for Superfund remediation technologies and models for estimating air emission rates from Superfund remedial actions. | TBC |
| <u>Location-Specific</u> | | |
| Groundwater Protection Strategy (EPA, 1984) | Groundwater beneath the VCM subplume is likely designated as Class II. | TBC |
| The Clean Air Act (CAA) Prevention of Significant Deterioration (PSD) Standards (40 CFR Part 52.21) | Although not classified as a major source, corrective measures alternatives (e.g., air stripping) may result in air emissions to the atmosphere. The Site is in a NAAQS non-attainment area for ozone. | Potentially Relevant and Appropriate |

TABLE 3.1

**FEDERAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>ARAR Citation</i> | <i>Rationale for Use</i> | <i>Type of Requirement</i> |
|--|--|---------------------------------|
| <u>Action-Specific</u> | | |
| Resource Conservation and Recovery Act (RCRA) | | |
| - Identification and Listing of Hazardous Waste (40 CFR Part 261) | Treatment residuals may be classified as characteristic hazardous waste. | Potentially Applicable |
| - Land Disposal Restrictions (LDRs) (40 CFR Part 268) | Disposal of treatment residuals which may be considered hazardous waste would be subject to land disposal restrictions. | Potentially Applicable |
| - Treatment, Storage, and Disposal of Hazardous Waste (40 CFR Parts 262-265, and 266) | During Site restoration, waste generation, transport, and/or treatment, storage, and disposal activities may occur. | Potentially Applicable |
| National Environmental Policy Act (NEPA) (40 CFR Part 6) | Consideration of environmental impacts of remedial actions will be addressed in the FS report. | Applicable |
| Control of Air Emissions from Superfund Air Strippers at Superfund Groundwater Sites (OSWER Directive 9355.0-28) | Site restoration at the Site may include air stripping and/or vapor extraction of groundwater. The Site is in a NAAQS non-attainment area for ozone. | TBC |
| General Pretreatment Regulations for Existing and New Sources of Pollutants (40 CFR Part 403) | Effluent from a groundwater treatment system for the Site may be discharged to a local POTW. | Potentially Applicable |
| Underground Injection Control Program (40 CFR Parts 144, 147) | Effluent from treatment of groundwater may be reinjected through recharge basins into the same formation from which it was withdrawn. | Potentially Applicable |
| OSHA Requirements (29 CFR Parts 1910, 1926, and 1904)* | Required for Site workers during construction and operation of remedial activities. | Must be met during remediation* |
| DOT Rules for Hazardous Materials Transport (40 CFR Parts 107, 171-179)* | Remedial actions may include off-Site treatment and disposal of treatment residuals (e.g., off-Site regeneration of activated carbon) as well as samples analysis. | Must be met during remediation* |

Note:

- * These requirements are not true ARARs under SARA since they are not environmental requirements and ARAR waiver cannot be obtained; however, these requirements must be met during remedial action.

TABLE 3.2

**PRELIMINARY STATE APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>ARAR Citation</i> | <i>Rationale for Use</i> | <i>Type of Requirement</i> |
|---|---|----------------------------|
| <u><i>Contaminant-Specific</i></u> | | |
| New York Ambient Air Quality Standards (6 NYCRR Parts 256 and 257) | The Site area is classified as Level III. Particulate and non-methane hydrocarbon standards will be applicable. | Applicable |
| New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700-704) | Standards impact selection of groundwater plume remediation goals, as well as treatment goals for reinjection of treated effluent to the aquifer. The Site groundwater is classified as GA. | Applicable |
| New York Public Water Supply Regulations (10 NYCRR Part 5) | Drinking water standards impact selection of groundwater remediation goals, as well as treatment goals for reinjection of treated effluent to the aquifer. | Applicable |
| <u><i>Action-Specific</i></u> | | |
| New York Environmental Conservation Law (ECL) (New York Consolidated Laws, Chapter 43-B): | | |
| - Water Pollution Control (ECL, Article 17) | Discharges to state groundwater are prohibited unless in compliance with all standards, criteria, limitation, rules, and regulations. | Potentially Applicable |
| - Air Pollution Control Act (ECL, Article 19) | Provides policy to maintain the quality of air resources of the state. Regulations provided in 6 NYCRR Parts 200 to 257. | Potentially Applicable |
| - New York Solid and Hazardous Waste Management Laws (ECL, Article 27) | Addresses solid and hazardous waste management. In addition, a preferred state-wide hazardous management practices hierarchy is provided. | Applicable |
| - Uniform Procedures (ECL, Article 70) | Establishes uniform review procedures for major regulatory programs. Procedures are provided for coordinating permitting for a project requiring one or more NYSDEC permit. | Applicable |
| New York Air Pollution Control Regulations (6 NYCRR Parts 200-254) | Remedial activities (e.g., air stripping, excavation, vacuum extraction) may adversely impact air quality. | Potentially Applicable |
| New York Waste Transport Permit Regulations (6 NYCRR Part 364) | Off-Site transport of treatment residuals will require compliance with these regulations. | Potentially Applicable |
| New York General Hazardous Waste Management System Regulations (6 NYCRR Part 370) | Residuals from treatment could be considered as hazardous waste subject to these regulations. | Potentially Applicable |

TABLE 3.2

**PRELIMINARY STATE APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>ARAR Citation</i> | <i>Rationale for Use</i> | <i>Type of Requirement</i> |
|---|---|--------------------------------------|
| New York Identification and Listing of Hazardous Wastes Regulations (6 NYCRR Part 371) | Treatment residuals generated at the Site may test to be characteristic hazardous wastes. | Potentially Applicable |
| New York State Air Guide (1991) | Provides guidance on calculating limits for offgas emissions. | To Be Considered (TBC) |
| New York Hazardous Waste Manifest System Regulations (6 NYCRR Part 372) | Manifests will be required for off-Site disposal/treatment of treatment residuals. | Potentially Applicable |
| New York Final Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (6 NYCRR Subpart 373-2) | Treatment and/or storage activities may take place on Site. | Potentially Relevant and Appropriate |
| New York Interim Status Standards for Owners and Operators of Hazardous Waste Facilities (6 NYCRR Subpart 373-3) | Treatment and/or storage activities may take place on Site. | Potentially Relevant and Appropriate |
| New York Standards for Managing Specific Hazardous Wastes and Hazardous Waste Management Facilities (6 NYCRR Part 374) | Although unlikely, remedial alternatives may include recovery. | Potentially Relevant and Appropriate |
| New York Land Disposal Restrictions Regulations (6 NYCRR Part 376) | Treatment residuals will be subject to land disposal restrictions if hazardous by characteristic. | Potentially Applicable |
| New York Rules on Hazardous Waste Program Fees (6 NYCRR Parts 483 and 484) | No hazardous waste program fees are payable related to cleanup, remediation, or corrective action activities. However, waste transporter program fees will be required for off-Site disposal of wastes or treatment residuals. | Potentially Applicable |
| New York Water Classifications and Quality Standards (6 NYCRR Parts 609, 700-704) | Treated groundwater may be reinjected to groundwater and would need to comply with Groundwater Effluent Standards. The Site is in Nassau County, so will additionally have to comply with a maximum concentration of 1,000 mg/L total dissolved solids (TDS) and 10 mg/L total nitrogen (as N). | Potentially Applicable |
| New York Technical Manual "Contained-In" Criteria for Environmental Media | May aid in establishing groundwater cleanup goals. These standards would allow groundwater to be treated to meet SPDES standards and discharged on Site even if the groundwater is determined to contain a listed hazardous constituent. | TBC |

TABLE 3.3

ARARs/TBCs FOR GROUNDWATER CHEMICALS OF CONCERN (µg/L)
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK

| Compound | RI Results | | | Federal Standards MCLs/MCLGs | NY State Standards | | NY State Guidance TAGM ^(f) | NY State GW Effluent Standard | PRG |
|--|----------------|--|-------------------------------|---------------------------------|---------------------------|-------------------------|--|--|-------------------|
| | CRQL/ CRDL | Location of Maximum Conc. ^(a) | Range of Detected Conc. | | | GW Quality Standards | | | |
| | | | | | | | | | |
| Volatile Organics (Geraghty & Miller, 1994; HNUS, 1994) | | | | | | | | | |
| Trichloroethene | 5 | HN24I | ND-58,000 | 5 (FMCL) | 5 | 5 | 5 | 10 | 5 |
| Toluene | 5 | HN29S | ND-39 | 1,000 (FMCL) | 5 | 5 | 5 | NA | 5 |
| 1,1-Dichloroethane | 5 | HN29S | ND-880 | --- | 5 | 5 | 5 | NA | 5 |
| 1,2-Dichloroethene | 5 | HN29S | ND-3,600 | 70 cis (FMCL) 100 trans | 5 | 5 | 5 (cis) ^(g) 5 (trans) ^(g) | NA | 5 |
| 1,1,1-Trichloroethane | 5 | HN29S | ND-10,000 | 200 (FMCL) | 5 | 5 | 5 | NA | 5 |
| Tetrachloroethene | 5 | HN-29S | ND-1,400 | 5 (FMCL) | 5 | 5 | 5 | NA | 5 |
| 1,1-Dichloroethene | 5 | GP-8 | ND-420 | 7 (FMCL) | 5 | 5 | 5 | NA | 5 |
| Carbon tetrachloride | 5 | HN24I | ND-8 | 5 (FMCL) | 5 | 5 | 5 | 5 | 5 |
| Xylenes | 5 | HN29S | ND-19 | 10,000 (FMCL) | 5 | 5 | 5 (ortho) 5 (meta) 5 (para) | NA | 5 |
| Vinyl chloride | 2 | MW-52I | ND-2,300 | 2 (FMCL) | 2 | 2 | 2 | NA | 2 |
| Semi-Volatile Organics (HNUS, 1994) | | | | | | | | | |
| Bis(2ethylhexyl)phthalate | 10 | GP-11 | ND-150 | 6 (FMCL) | 50 | 50 | 50 | 4,200 | 6 |
| Total Phenols ^(h) | 10(individual) | HN29S | ND-11 J | --- | 50 | 1 (total phenols) | 1 (total phenols) | NA | 1 (total phenols) |
| Benzo(b)fluoranthene | 10 | USGS N10623 ⁽ⁱ⁾ | ND-2 J | 0.2 (PMCL) | 50 | --- | 0.002 | NA | 0.002 (TOGS) |
| Inorganics (Total) (HNUS, 1994) (Legette, Brashears, & Graham, Inc. 1990) (Geraghty and Miller, 1994) ^(g) | | | | | | | | | |
| Aluminum | 200 | HN27S | ND-33,800 | 200 (FSMCL) | --- | --- | --- | 2,000 | 200 (FMCL) |
| Arsenic | 10 | K-2 | ND-59 | 50 (Review) | 50 | 25 | 25 | 50 | 25 |
| Cadmium | 5 | HN27S | ND-392 | 5 (FMCLG) | 10 | 10 | 5 ^(g) | 20 | 5 |
| Chromium, Total | 10 | HN27S | ND-169 | 100 (FMCLG) | 100 | 50 | 50 | NA | 50 |
| Chromium, Hexavalent | 10 | HN25 | ND-174 J | --- | --- | 50 | 50 | 100 | 50 |
| Copper | 100 | GM13S | ND-838 J | 1,300 (FMCLG) | 1,000 (SMCL) | 200 | 200 | 1,000 | 200 |
| Iron | 3 | GM15S | 114-229,000 | 300 (FSMCL) | 300 (SMCL) ^(e) | 300 ^(e) | 300 ^(e) | 600 | 300 |
| Lead | 5,000 | GM15S | ND-169 | 15 (Action Level) | 15 (Action Level) | 25 | 15 ^(g) | 50 | 15 |

TABLE 3.3

ARARs/TBCs FOR GROUNDWATER CHEMICALS OF CONCERN (µg/L)
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK

| Compound | RI Results | | Federal Standards MCLs/MCLGs | NY State Standards | | NY State Guidance TAGM ^(f) | NY State GW Effluent Standard | PRG |
|-----------|---------------|--|---------------------------------|-------------------------------|---------------------------|--|--|-------------|
| | CRQL/ CRDL | Location of Maximum Conc. ^(a) | | Range of Detected Conc. | MCLs ^{(b)(c)} | | | |
| Manganese | 0.2 | GM13S | 200 (LMCLG) | 7.65-1,720 J | 300 (SMCL) ^(e) | 300 ^(e) | 600 | 200 (LMCLG) |
| Thallium | 50 | HN24I | 2 (FMCL) | ND-3.1 J | --- | --- | NA | 2 (FMCL) |
| Vanadium | 20 | HN29S | --- | ND-419 | --- | --- | NA | 250 |
| Cyanide | --- | HN27S | 200 (FMCL) | ND-2,690 | --- | 100 | 400 | 100 (FMCL) |
| Nickel | 5,000 | GM13S | 100 (FMCL) | ND-132 | --- | --- | 2,000 | 100 (FMCL) |

Notes:

- - Not Detected
- F - Final
- L - Listed
- P - Proposed
- S - Secondary
- CRDL - Contract Required Detection Limit
- CRQL - Contract Required Quantitation Limit
- IDL - Instrument Detection Limit
- MCL - Maximum Contaminant Level
- MCLG - Maximum Contaminant Level Goals
- PRG - Preliminary Remedial Action Goal = most stringent of FMCLs Groundwater Quality Standard or Contained in Policy.
- (a) - Includes data from all sampling rounds since 1990.
- (b) - Total Principal Organic Contaminants (POCs) (i.e., includes listed volatile organics and Unspecified Organic Contaminants (UOCs) not to exceed 100 µg/L total.
- (c) - Reference: New York Public Supply Regulations, Part 5-1, 07/17/92
- (d) - Reference: New York Water Classifications and Quality Standards, Title 6, Chapter V, Part 703.
- (e) - Combined concentration of iron and manganese shall not exceed 500 µg/L. Iron and manganese not to exceed 300 µg/L.
- (f) - Reference: New York Technical Manual, "Contained In" Criteria for Environmental Media.
- (g) - Only monitoring wells on NWIRP property (designated with prefix HN-) and Hooker/Ruco Site (such as K-2) were sampled and analyzed for semi-VOCs.
Only a summary of analytical data is available from the Hooker/Ruco Site.
- (h) - Total Phenols = 2-Methylphenol + 4-Methylphenol + 2,4-Dimethylphenol.
- (i) - Benzo(b)fluoranthene was detected only in USGS well N10623. This detection is suspected to be due to runoff from a nearby asphalt road through leakage in the well cap.

TABLE 3.4

**INITIAL IDENTIFICATION AND SCREENING OF TECHNOLOGIES/PROCESS OPTIONS (GENERAL APPLICABILITY)
FOR GROUNDWATER TREATMENT
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>General Response Action</i> | <i>Technology</i> | <i>Process Options</i> | <i>Description</i> | <i>General Screening</i> |
|------------------------------------|------------------------|------------------------------|--|------------------------------|
| No Action | No Action | No Action | Present conditions are allowed to continue | x ⁽¹⁾ |
| Institutional Controls | Institutional Controls | Fencing | Barrier used to restrict Site access | x ⁽²⁾ |
| | | Deed Restrictions | Administrative action used to restrict future groundwater use | * |
| | | Monitoring | Sampling and analysis of media to assess contaminant migration | * |
| | | Alternative Water Supply | Replacement of contaminated groundwater source with alternative water supply for end user | x ⁽³⁾ |
| Containment | Capping | Capping | Use of impermeable or semi-permeable materials to reduce the vertical migration of contaminants from source areas into groundwater | * |
| | Vertical Barriers | Slurry Walls | Clay wall used to restrict horizontal migration of contaminants in groundwater | x ⁽⁴⁾ |
| | | Jet Grouting | Use of pressure-injected cement to restrict horizontal migration of contaminants in groundwater | x ⁽⁴⁾ |
| Removal | Extraction | Extraction Wells | Discrete pumping wells used to remove contaminated water | * |
| | | Collection Trench | A permeable trench used to intercept and collect groundwater | x ⁽⁴⁾ |
| | Enhanced Removal | Enhanced Removal | Blasting or hydrofracturing of bedrock to promote access to groundwater in bedrock fractures | x ⁽⁵⁾ |
| Disposal | Beneficial Re-use | Process Water/ Potable Water | On-Site re-use of groundwaters in which the contaminants have been removed | * |
| | Surface Discharge | Direct Discharge (NPDES) | Discharge of collected/treated water to a local surface water | x ⁽⁶⁾ |
| | | Indirect Discharge (POTW) | Discharge of collected/treated water to a publicly owned treatment works | * |
| | | Off-Site Treatment Facility | Treatment and disposal of hazardous or nonhazardous materials at permitted off-Site facilities | x ⁽⁷⁾ |
| | Subsurface Discharge | Reinjection/SPDES Discharge | Use of reinjection, spray irrigation, or infiltration to discharge collected/treated groundwater to underground | * |

TABLE 3.4

**INITIAL IDENTIFICATION AND SCREENING OF TECHNOLOGIES/PROCESS OPTIONS (GENERAL APPLICABILITY)
FOR GROUNDWATER TREATMENT
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>General Response Action</i> | <i>Technology</i> | <i>Process Options</i> | <i>Description</i> | <i>General Screening</i> |
|------------------------------------|-------------------|----------------------------|--|------------------------------|
| Treatment | Physical | Extraction | Separation of contaminants from a solution by contact with an immiscible liquid with a higher affinity for the contaminants of concern | x ⁽⁸⁾ |
| | | Dewatering | Mechanical removal of free water from wastes using equipment such as a filter press or a vacuum filter | * |
| | | Sedimentation | Gravity settling of suspended solids from water in a vessel | * |
| | | Equalization | Dampening of flow and/or contaminant concentration variation in a large vessel to promote constant discharge rate and water quality | * |
| | | Filtration | Separation of materials from water via entrapment in a bed or membrane separation | * |
| | | Flotation | Separation of oils and suspended solids less dense than water by flotation methods | x ⁽⁹⁾ |
| | | Reverse Osmosis | Use of high pressure and membranes to separate dissolved materials, including organics and inorganics from water | * |
| | | Volatilization | Contact of contaminated water with air to remove volatile compounds. Air stripping or steam stripping methods are typically employed | * |
| | | Adsorption | Adsorption of contaminants onto activated carbon, resins, or activated alumina | * |
| | | Evaporation | Change from the liquid to the gaseous state at a temperature below the boiling point | x ⁽⁸⁾ |
| | | Distillation | Vaporization of a liquid followed by condensation of the vapors by cooling | x ⁽⁸⁾ |
| | | Electrodialysis | Recovery of anions or cations using special membranes under the influence of an electrical current | x ⁽⁸⁾ |
| | Biological | Aerobic | Suspended growth or fixed film process employing aeration and biomass recycle to decompose organic components | x ⁽¹⁰⁾ |
| | | Aerobic/Anaerobic | Suspended growth facultative process in pond or basin employing long detention times and aerobic/anaerobic biomass to decompose organic contaminants | x ⁽¹⁰⁾ |

TABLE 3.4

INITIAL IDENTIFICATION AND SCREENING OF TECHNOLOGIES/PROCESS OPTIONS (GENERAL APPLICABILITY)
FOR GROUNDWATER TREATMENT
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK

| <i>General Response Action</i> | <i>Technology</i> | <i>Process Options</i> | <i>Description</i> | <i>General Screening</i> |
|------------------------------------|-------------------|------------------------------|--|------------------------------|
| In Situ Treatment | Chemical | Anaerobic | Suspended growth or fixed film process employing anaerobic biomass to decompose organic contaminants | x ⁽¹⁰⁾ |
| | | Ion Exchange | Process in which ions, held by electrostatic forces, to charged functional groups on the ion exchange resin surface, are exchanged for ions of similar charge in a water stream | * |
| | | Electrolytic Recovery | Passage of an electric current through a solution with resultant ion recovery on positive and negative electrodes | x ⁽⁸⁾ |
| | | Enhanced Oxidation | Use of strong oxidizers such as ultraviolet light, ozone, peroxide, chlorine, or permanganate to chemically oxidize materials. Typically hydrogen peroxide (and/or ozone) with UV light is utilized for groundwater remediation. Oxidation may also be accomplished through the use of high temperatures, pressures, and air | * |
| | | Reduction | Use of strong reducers such as sulfur dioxide, sulfite, or ferrous iron to chemically reduce the oxidation state of materials | * |
| | | pH Adjustment | Use of acids or bases to counteract excessive pHs or to adjust pH to optimum for a given technology | * |
| | | Dechlorination | Use of chemicals to remove chlorine from chlorinated compounds | x ⁽⁸⁾ |
| | Chemical/Physical | Flocculation/ Coagulation | Use of chemicals to neutralize surface charges and promote attraction of colloidal particles to facilitate settling | * |
| | | Precipitation | Use of reagents to convert soluble materials into insoluble materials | * |
| | | Soil Flushing | Flushing of contaminants using an injection/extraction well system and above-ground treatment system | * |
| | Biological | Chemical Oxidation | Addition of oxidant (potassium permanganate) to groundwater interval, oxidant reacts with VCM to form carbon dioxide, water, potassium chloride and manganese oxide | * |
| | | Biosparging | Innovative technology that uses dispersion of air into the groundwater formation to create an "air lift affect" that strips VCM from groundwater as the air rises to the vadose zone | * |

400191

TABLE 3.4

INITIAL IDENTIFICATION AND SCREENING OF TECHNOLOGIES/PROCESS OPTIONS (GENERAL APPLICABILITY)
FOR GROUNDWATER TREATMENT
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK

| <i>General Response Action</i> | <i>Technology</i> | <i>Process Options</i> | <i>Description</i> | <i>General Screening</i> |
|------------------------------------|-------------------|----------------------------|---|------------------------------|
| In Situ Treatment (Cont'd.) | | Bioremediation | Passive in situ biodegradation process, which uses a combination of modeling and monitoring to demonstrate that downgradient receptors are not impacted | * |
| | | Enhanced Bioremediation | Chemical oxidation and addition of nutrients to enhance aerobic degradation | * |

Notes:

- * - Potentially applicable.
- x - Not applicable.
- (1) - No action retained for baseline comparison purposes.
- (2) - Fencing is already in place at the site and would not prevent migration of/access to groundwater contaminants.
- (3) - Deleted based on large volume users and lack of another potable water source.
- (4) - Aquifer is too deep to implement an effective vertical barrier or permeable trench. Unrestricted groundwater flow exists to a depth of several hundred feet.
- (5) - Aquifer is sufficiently permeable so as not to require enhanced removal.
- (6) - There are no local surface waters for discharge purposes.
- (7) - Volume of contaminated groundwater is too large to effectively transport and treat off Site.
- (8) - These technologies are typically utilized for high concentration wastewater streams and are rarely utilized for groundwater remediation.
- (9) - No floating products are located in the groundwater.
- (10) - Metals are not readily amenable to biodegradation. The end point of biodegradation of chlorinated aliphatics (e.g., PCE and TCE) for reducing conditions is ethenes/ethanes, and for oxidizing conditions is carbon dioxide.

400192

TABLE 3.5

**SUMMARY OF COMPARATIVE TECHNOLOGY SCREENING
FOR SITE GROUNDWATER
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>Remedial Action</i> | <i>Technology</i> | <i>Process Option</i> | <i>Effectiveness</i> | <i>Implementability</i> | <i>Cost</i> | <i>Retain/ Eliminate</i> |
|------------------------|------------------------|------------------------------|--|---|---|------------------------------|
| In Situ Treatment | Chemical / Physical | Adsorption | Handles Volume – High Reliability – Low Protectiveness – Low Meets Goals - Low | TSD Availability – High Equipment/Resources – High Acquire Permits - High | Capital – Low O&M – High | Eliminate |
| | | Soil Flushing | Handles Volume - Medium Reliability– Low Protectiveness – Medium Meets Goals - Medium | TSD Availability – NA Equipment/Resources – Medium Acquire Permits - Medium | Capital – Medium O&M – Medium | Eliminate |
| | | In-Well Biosparging | Handles Volume – Medium Reliability – Medium Protectiveness – Medium Meets Goals - Medium | TSD Availability – NA Equipment/Resources – Medium Acquire Permits - Medium | Capital – Low to Medium O&M – Medium | Retain |
| | | Chemical Oxidation | Handles Volume - Medium Reliability– Medium Protectiveness – Medium Meets Goals - Medium | TSD Availability – NA Equipment/Resources – Medium Acquire Permits - Medium | Capital – Low to Medium O&M – Medium | Retain |
| | | Bioremediation (enhanced) | Handles Volume – High Reliability – Medium Protectiveness – Medium Meets Goals - Medium | TSD Availability – NA Equipment/Resources – High Acquire Permits - High | Capital – Low to Medium O&M – Medium | Retain |

400193

TABLE 3.5

**SUMMARY OF COMPARATIVE TECHNOLOGY SCREENING
FOR SITE GROUNDWATER
HOOKER/RUCO SITE
HICKSVILLE, NEW YORK**

| <i>Remedial Action</i> | <i>Technology</i> | <i>Process Option</i> | <i>Effectiveness</i> | <i>Implementability</i> | <i>Cost</i> | <i>Retain/ Eliminate</i> |
|-------------------------------------|-------------------|---|--|---|---|------------------------------|
| No Further Action - Northrop IRM | No Further Action | No Further Action | Handles Volume - High Reliability - Low Protectiveness - Low Meets Goals - Medium | TSD Availability - High Equipment/Resources - High Acquire Permits - High | Capital - Low O&M - Low | Retain |
| Removal | Extraction | Extraction Wells | Handles Volume - High Reliability - High Protectiveness - High Meets Goals - Medium | TSD Availability - NA Equipment/Resources - High Acquire Permits - High | Capital - Medium O&M - Medium | Retain |
| Treatment | Physical | Dewatering | Handles Volume - High Reliability - Low Protectiveness - Low Meets Goals - Low | TSD Availability - Medium Equipment/Resources - High Acquire Permits - High | Capital - High O&M - Medium | Eliminate |
| | | Volatilization (counter-current Packed tower) | Handles Volume - High Reliability - High Protectiveness - High Meets Goals - High | TSD Availability - Medium Equipment/Resources - High Acquire Permits - Medium | Capital - Medium O&M - Low to Medium | Retain |
| | | Volatilization (open basin with Mixer/diffuser/ Bubbler) | Handles Volume - Medium Reliability - High Protectiveness - High Meets Goals - High | TSD Availability - Medium Equipment/Resources - High Acquire Permits - Medium | Capital - Low to Medium O&M - Low to Medium | Eliminate |

400194

APPENDIX A
HYDROGEOLOGIC MODELING

TABLE OF CONTENTS

| | <u>Page</u> |
|--|-------------|
| 1.0 INTRODUCTION..... | A-1 |
| 2.0 HYDROGEOLOGIC MODELING PROGRAM SELECTION | A-3 |
| 3.0 PREDICTIVE HYDROGEOLOGIC SIMULATIONS..... | A-4 |
| 3.1 CONTAMINANT TRANSPORT SIMULATION | |
| INPUT PARAMETERS AND SOLUTION METHOD | A-4 |
| 3.1.1 INPUT PARAMETERS..... | A-4 |
| 3.1.2 SOLUTION METHOD | A-6 |
| 3.2 ALTERNATIVE 2: ENHANCED NORTHROP IRM | A-7 |
| 3.3 ALTERNATIVE 3A: MW-52 AREA SYSTEM | |
| TO ACHIEVE MASS REDUCTION | A-8 |
| 3.4 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs | A-9 |
| 4.0 REFERENCES..... | A-12 |

LIST OF FIGURES
(Following Text)

- FIGURE A.3.1 VCM DISTRIBUTION IN THE SHALLOW ZONE (<100 feet BGS)
- FIGURE A.3.2 VCM DISTRIBUTION IN THE INTERMEDIATE ZONE
(100 TO 180 feet BGS)
- FIGURE A.3.3 VCM DISTRIBUTION IN THE DEEP ZONE (180 TO 270 feet BGS)
- FIGURE A.3.4 VCM DISTRIBUTION IN THE VERY DEEP ZONE (>270 feet BGS)
- FIGURE A.3.5 ALTERNATIVE 2: ENHANCED NORTHROP IRM
SIMULATED VCM CONCENTRATION PROFILE AT GP-1
UNDER NORTHROP IRM
- FIGURE A.3.6 ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE MASS
REDUCTION; HYDRAULIC CONTAINMENT OF SHALLOW VCM
IMPACT
- FIGURE A.3.7 ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE MASS
REDUCTION, HYDRAULIC CONTAINMENT OF INTERMEDIATE VCM
IMPACT
- FIGURE A.3.8 ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE MASS
REDUCTION, HYDRAULIC CONTAINMENT OF DEEP VCM IMPACT
- FIGURE A.3.9 ALTERNATIVE 3A: V MW-52 AREA SYSTEM TO ACHIEVE MASS
REDUCTION, HYDRAULIC CONTAINMENT OF VERY DEEP VCM
IMPACT
- FIGURE A.3.10 ALTERNATIVE 3A: 7.5-YEAR PUMPING OF MW-52 AREA SYSTEM TO
ACHIEVE MASS REDUCTION, SIMULATED VCM CONCENTRATION
PROFILES
- FIGURE A.3.11 ALTERNATIVE 3A: 5-YEAR PUMPING OF MW-52 AREA SYSTEM TO
ACHIEVE MASS REDUCTION, SIMULATED VCM CONCENTRATION
PROFILES
- FIGURE A.3.12 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION PROFILES
- FIGURE A.3.13 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 1

LIST OF FIGURES
(Following Text)

- FIGURE A.3.14 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 2
- FIGURE A.3.15 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 3
- FIGURE A.3.16 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 4
- FIGURE A.3.17 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 5
- FIGURE A.3.18 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 6
- FIGURE A.3.19 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 7
- FIGURE A.3.20 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 8
- FIGURE A.3.21 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 9
- FIGURE A.3.22 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 10
- FIGURE A.3.23 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 11
- FIGURE A.3.24 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs,
SIMULATED VCM CONCENTRATION IN LAYER 12

LIST OF TABLES
(Following Text)

| | |
|-------------|--|
| TABLE A.3.1 | NORTHROP IRM PUMPING AND DISCHARGE RATES |
| TABLE A.3.2 | ALTERNATIVE 2: ENHANCED NORTHROP IRM PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL |
| TABLE A.3.3 | ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE TO ACHIEVE MASS REDUCTION, PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL |
| TABLE A.3.4 | ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs, PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL |

1.0 INTRODUCTION

This appendix presents the hydrogeologic modeling of the Bethpage regional aquifer conducted by Conestoga-Rovers & Associates (CRA) on behalf of Occidental Chemical Corporation (OxyChem) and Glenn Springs Holdings Inc. (GSHI) in conjunction with the Feasibility Study, Operable Unit-3 (OU-3 FS) for the Hooker Chemical/Ruco Polymers Superfund Site (Hooker/Ruco Site). The hydrogeologic modeling was conducted to evaluate the impact of the Northrop/Grumman Aerospace Corporation (Northrop) Interim Remedial Measure (IRM) on groundwater conditions in the vicinity of the Hooker/Ruco Site, and to evaluate the impact of pumping from the MW-52 area groundwater extraction system (MW-52 area system). Specifically, the hydrogeologic modeling was conducted to assess the following:

- the extent of southward vinyl chloride monomer (VCM) migration in groundwater under the influence of the Northrop IRM. This assessment was conducted in conjunction with Alternative 2 evaluated in the OU-3 FS;
- the duration of pumping from the MW-52 area system required such that VCM concentrations in groundwater extracted by the Northrop IRM groundwater extraction well GP-1 do not exceed concentrations that require supplemental treatment of the GP-1 effluent to prevent an exceedance of the Air Guide 1 VCM criterion of 0.02 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). This assessment was conducted in conjunction with Alternative 3A evaluated in the OU-3 FS; and
- the duration of pumping from the MW-52 area system required such that VCM concentrations in the vicinity of monitoring well MW-52 are reduced to the Maximum Concentration Limit (MCL) of 2 micrograms per liter ($\mu\text{g}/\text{L}$) for VCM. This assessment was conducted in conjunction with Alternative 3B evaluated in the OU-3 FS.

The hydrogeologic modeling was conducted using the calibrated groundwater flow model of the Bethpage regional aquifer developed for Northrop by Geraghty & Miller, Inc. (G&M). The G&M calibrated groundwater flow model was developed using the United States Geological Survey's (USGS's) three-dimensional finite-difference groundwater flow model MODFLOW (McDonald and Harbaugh, 1988). The computer files associated with the G&M calibrated groundwater flow model were provided to OxyChem by G&M on June 9, 1995. G&M subsequently made minor revisions to the boundary conditions of the G&M calibrated groundwater flow model. The computer files associated with the updated version of the G&M calibrated groundwater flow model were provided to OxyChem by G&M on April 29, 1996. The computer files

associated with the updated G&M calibrated groundwater flow model were used to conduct the predictive hydrogeologic simulations presented herein.

G&M has prepared detailed documentation of the G&M calibrated groundwater flow model in the document entitled, "Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York" (G&M Model Documentation) (G&M, 1997). A detailed description of the G&M calibrated groundwater flow model, and the G&M Model Documentation, are presented in Appendices H and I, respectively, of the report entitled, "Draft Remedial Investigation Report, Operable Unit-3, Hooker/Ruco Site, Hicksville, New York" (OU-3 RI Report) (CRA, 1999).

The G&M calibrated groundwater flow model was applied in the VCM migration simulations associated with the assessment of Alternatives 2, 3A, and 3B evaluated in the OU-3 FS. The coarse horizontal and vertical discretization of the G&M calibrated groundwater flow model, while adequate for the simulation of groundwater flow, would create significant numerical errors during the solution of the advection-dispersion equation. The horizontal and vertical discretization of the G&M calibrated groundwater flow model were refined to reduce this numerical error such that its impact on the VCM migration simulation was not significant. The refinement of the G&M calibrated groundwater flow model discretization is presented in Section 5.1 of Appendix H of the OU-3 RI Report. The refined model consists of 12 layers. The approximate vertical location of each refined model layer in the vicinity of the Hooker/Ruco is presented in Table H.5.1 of Appendix H of the OU-3 RI Report. The VCM migration simulations presented in this appendix were conducted using the refined model.

This appendix is organized as follows:

- Section 1: presents the introduction to, and purpose of, the hydrogeologic modeling conducted for the OU-3 FS;
- Section 2: presents a description of the hydrogeologic modeling programs selected to conduct the predictive hydrogeologic simulations for the OU-3 FS;
- Section 3: presents the application of the refined G&M calibrated groundwater flow model to conduct the hydrogeologic simulations associated with the assessment of Alternatives 2, 3A, and 3B evaluated in the OU-3 FS; and
- Section 4: presents a list of references cited herein.

2.0 HYDROGEOLOGIC MODELING PROGRAM SELECTION

Appropriate simulation programs were selected based upon the purpose and scope of groundwater flow and contaminant transport model applied in this modeling study. The primary considerations in the program selection included the ability of the program to represent the key components of the conceptual groundwater flow model, the demonstrated verification that the program correctly simulates the hydrogeologic processes being considered, and the proven acceptance of the program by regulatory agencies and the scientific/engineering community.

The following programs were selected to conduct hydrogeologic modeling presented in this appendix:

- MODFLOW-96: A fully three-dimensional finite-difference transient groundwater flow model developed by the USGS (Harbaugh and McDonald, 1996). MODFLOW-96 is an updated version of USGS's original version of MODFLOW developed by McDonald and Harbaugh (1988);
- PATH3D: A fully three-dimensional transient particle tracking model developed by S.S. Papadopoulos & Associates (Zheng, 1991) that works in conjunction with MODFLOW-96; and
- MT3DMS: A fully three-dimensional finite-difference transient solute mass transport model developed for the US Army Corps of Engineers by Zheng and Wang (1998) that works in conjunction with MODFLOW-96. MT3DMS is an updated version of MT3D developed by Zheng (1992).

These programs have been extensively verified and have been readily accepted by many regulatory agencies throughout the United States.

The pre-processor Groundwater Vistas (Environmental Simulations Inc., 1996) was applied as a graphical user interface between the simulation model and the required MODFLOW-96, PATH3D, and MT3DMS program input files.

3.0 PREDICTIVE HYDROGEOLOGIC SIMULATIONS

The refined G&M calibrated groundwater flow model was applied to conduct the predictive hydrogeologic simulations associated with the assessment of Alternatives 2, 3A, and 3B evaluated in the OU-3 FS. Descriptions of the applied contaminant transport simulation input parameters and solution method are presented in Section 3.1. Descriptions of the predictive hydrogeologic simulations conducted for Alternatives 2, 3A, and 3B are presented in Sections 3.2, 3.3, and 3.4, respectively.

3.1 CONTAMINANT TRANSPORT SIMULATION INPUT PARAMETERS AND SOLUTION METHOD

3.1.1 INPUT PARAMETERS

The simulation of VCM migration for each alternative was conducted by applying the estimated VCM distribution in the vicinity of the Hooker/Ruco Site and MW-52 area for the following four depth zones: shallow (<100 ft BGS), intermediate (100 to 180 ft BGS), deep (180 to 270 ft BGS), and very deep (>270 ft BGS). A conservative estimate of the areal distribution of VCM in each depth zone was determined based on the most recent VCM concentrations detected in each zone. The estimated VCM distribution in the shallow, intermediate, deep, and very deep zones are presented on Figures A.3.1, A.3.2, A.3.3, and A.3.4, respectively. The observed VCM concentrations used to develop the estimated VCM distribution in each zone are presented on these figures.

The estimated VCM distributions were applied as initial VCM concentrations (i.e., at a simulation time of zero) in the refined model layers corresponding to the shallow, intermediate, deep, and very deep zones. The VCM distribution estimated for the shallow zone was assigned as the initial condition in the refined model layers 1 and 2. The VCM distribution estimated for the intermediate zone was assigned as the initial condition in the refined model layer 3. The VCM distribution estimated for the deep zone was assigned as the initial condition in the refined model layers 4 and 5. The VCM distribution estimated for the very deep zone was assigned as the initial condition in the refined model layers 6, 7, 8, and 9.

The migration of the initial VCM distributions was simulated with time under the influence of the various remedial alternatives assessed in the OU-3 FS. For each of Alternatives 2, 3A, and 3B, the migration of the initial VCM concentrations was simulated for an 80-year time period under the steady-state groundwater flow conditions associated with each alternative. The processes of advection, dispersion, and

retardation due to chemical sorption onto soil particles were represented in the VCM migration simulations. The selection of the contaminant transport input parameters associated with the representation of these processes is presented below.

The process of advection is governed by groundwater flow velocity. Groundwater flow velocities for the VCM migration simulations for Alternatives 2, 3A, and 3B were determined by applying a porosity value of 0.3. The groundwater flow velocities were calculated based on the steady-state groundwater flow conditions associated with each alternative.

The process of physical dispersion is governed by the dispersivity of the aquifer material combined with groundwater flow velocity. A value of 30 feet was applied for the longitudinal dispersivity, and values of 3 and 0.3 feet were applied for the transverse horizontal and transverse vertical dispersivities, respectively. Transverse horizontal and transverse vertical dispersivity values are typically approximated as 10 percent and 1 percent, respectively, of the longitudinal dispersivity value (Zheng and Bennett, 1995). In a study of reported field-scale dispersivity values, Gelhar et al. (1992) suggest that longitudinal dispersivity values generally range between one and two orders of magnitude less than the observed length, or scale, of an existing contaminant plume. However, as the plume length, or scale, increases to distances greater than 300 to 500 feet, the longitudinal dispersivity values with a high degree of reliability tend to plateau at an approximate value of 30 feet. The maximum VCM plume length is approximately 2,000 feet, based on the estimated VCM distribution in the deep zone shown on Figure A.5.16. As a result, a longitudinal dispersivity value of 30 feet was selected for the VCM migration simulation in consideration of the findings of Gelhar et al. (1992).

The process of chemical sorption is governed by the organic carbon partitioning coefficient of the compound under consideration, and the fraction of organic carbon content of the aquifer soil material. An organic carbon partitioning coefficient value of 11 milliliters per gram (mL/g) (Salhota et al., 1993) was applied for VCM. A fraction of organic carbon content value of 0.002 was considered representative of the sand and gravel deposits of the Upper Glacial and Mathogy aquifers that comprise the Bethpage regional aquifer. Assuming a dry soil bulk density value for the sand and gravel deposits of 1.9 grams per cubic centimeter (g/cm^3) and a porosity value of 0.3 provides a retardation factor value of 1.14 for VCM. This retardation factor was applied in the VCM migration simulations.

The effect of in situ remediation, or biodegradation, was not represented in the VCM migration simulations. Without this process, the simulated VCM concentrations were

not subject to reductions because of naturally occurring, or augmented, biodegradation. Because naturally occurring biodegradation processes are active in most subsurface environments, the simulated VCM concentrations are higher than those that would be estimated if it had been included in the simulations. These are conservative representations of VCM migration which provided higher estimated VCM concentrations at the Northrop IRM extraction wells and the MW-52 area system extraction wells.

3.1.2 SOLUTION METHOD

Contaminant transport simulations often are plagued by numerical dispersion or artificial oscillation caused by round-off error during the solution of the advection-dispersion equation. Numerical dispersion and oscillation result in the artificial spreading and dilution of simulated concentrations, and can lead to significantly non-conservative results when estimating a simulated concentration profile at an extraction well. Although the horizontal and vertical discretization of the G&M calibrated groundwater flow model was reduced in the refined model used to conduct the VCM migration simulations, an evaluation was conducted to ensure that the simulated results were not significantly impacted by numerical dispersion. The evaluation was conducted by solving the advection-dispersion equation using both the method of characteristics (MOC) and the finite-difference solution methods.

The MOC solution method is particle tracking based with the advantage that it is virtually free of numerical dispersion. However, MOC can lead to large mass balance discrepancies because the particle tracking technique does not guarantee local mass balance between time steps. The standard finite-difference solution method suffers from numerical dispersion and artificial oscillations when the chemical transport becomes advection dominated, as normally is the case in the vicinity of groundwater extraction wells. In order to minimize significant numerical dispersion with the standard finite-difference technique, time step sizes often are required to be extremely small creating simulation run times of impractical length. In this evaluation, a higher-order finite-difference method, referred to as the total-variation-diminishing (TVD) method (Zheng and Wang, 1998), was applied as implemented in MT3DMS. Like the standard finite-difference method, the TVD method conserves mass and has the added benefit that it does not result in excessive numerical dispersion and it is essentially oscillation free. In addition, time step sizes for the TVD method can be increased such that manageable simulation run times can be achieved.

To demonstrate that the VCM simulations presented herein were not significantly impacted by numerical dispersion, the results of the VCM migration simulations conducted using both the MOC and TVD methods are presented.

3.2 ALTERNATIVE 2: ENHANCED NORTHROP IRM

For Alternative 2, the migration of VCM under the Northrop IRM was simulated over an 80-year time period. The pumping and discharge rates associated with the Northrop IRM are presented in Table A.3.1. The application of the Northrop IRM pumping and discharge rates in the refined model for Alternative 2 is presented in Table A.3.2. The simulated VCM concentration profiles at GP-1 over the 80-year time period, reflecting the simulated VCM concentrations in the groundwater extracted from GP-1, determined using both the MOC and TVD methods are presented on Figure A.3.5. Relatively insignificant simulated VCM concentrations result at the Northrop IRM extraction wells ONCT-1, ONCT-2, and ONCT-3 (i.e., $<1 \mu\text{g/L}$). The simulated VCM concentration profile resulting from the TVD method closely follows the simulated VCM concentration profile resulting from the MOC method, although the TVD VCM profile does lie slightly below the MOC VCM profile. The jaggedness in the MOC VCM profile is a typical trait of the MOC method and is a result of the frequent redistribution of particles used in the particle tracking algorithm applied in the MOC solution. The mass balance error for the MOC solution remained below 1 percent for the first 20 years of the simulation, then increased to 5 percent between years 20 and 50, and increased to 10 percent over the remaining 30 years of the simulation. The mass balance errors for the MOC solution demonstrate that the simulation suffered from some mass conservation difficulties, as is often the case for the MOC method. The mass balance error for the entire TVD solution was less than 0.03 percent indicating that an acceptable mass balance was achieved with this solution technique. Despite the mass balance problems associated with the MOC method, the close agreement between the TVD and the MOC VCM profiles at GP-1 demonstrates that the TVD finite-difference solution provides a reasonable prediction of the VCM profile at GP-1 that was not significantly impacted by numerical dispersion.

A VCM concentration of $8.3 \mu\text{g/L}$ in groundwater extracted from GP-1 [at a GP-1 pumping rate of 1,100 gallons per minute (gpm)] will result in an exceedance of the Air Guide 1 VCM criterion of $0.02 \mu\text{g/m}^3$ at GP-1. VCM concentrations greater than $8.3 \mu\text{g/L}$ in groundwater extracted from GP-1 will require that supplemental treatment be added to the GP-1 groundwater treatment system to prevent an Air Guide 1 exceedance. Based on the VCM concentration profile at GP-1 simulated using the TVD

method, a VCM concentration of 8.3 µg/L in groundwater extracted from GP-1 will be exceeded in approximately 44 years.

3.3 ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION

Alternative 3A involves pumping from the MW-52 area system to remove sufficient VCM mass such that VCM from the MW-52 area will not migrate to the Northrop IRM at concentrations that would require supplemental VCM treatment at GP-1. Specifically, Alternative 3A involves pumping from the MW-52 area system for a time period sufficient to prevent the occurrence of VCM concentrations at GP-1 that exceed 8.3 µg/L. The MW-52 area system consists of the three groundwater extraction wells SPPW-1, SPPW-2, and SPPW-3. The location of SPPW-1 is approximately 500 feet south of MW-52 and a pumping rate of 500 gpm is proposed for this extraction well. The locations of SPPW-2 and SPPW-3 are approximately 1000 feet south of MW-52 and a pumping rate of 50 gpm is proposed from each of these extraction wells. The location of SPPW-2 was simulated at the Northrop production well GP-6. The discharge of treated groundwater from the MW-52 area system is proposed at Sumps 1 and 2 located in the southeast portion of the Hooker/Ruco Site at a rate of 50 gpm to each sump. The discharge of the remaining treated groundwater (500 gpm) is proposed at a new sump to be located in the northwest portion of the Hooker/Ruco Site. The pumping and discharge rates for Alternative 3A associated with the MW-52 area system and the Northrop IRM as applied in the refined model are presented in Table A.3.3.

The MW-52 area system extraction well locations and pumping rates were selected to provide hydraulic containment of the VCM impact in the MW-52 area. Particle tracking simulations were conducted using PATH3D to evaluate the extent of hydraulic containment achieved by the MW-52 area system. Particles were released around the limit of the estimated VCM impact in the shallow, intermediate, deep, and very deep zones presented on Figures A.3.1, A.3.2, A.3.3, and A.3.4, respectively, corresponding to the refined model layers 1, 3, 4, and 6. The movement of these particles was simulated under the steady-state groundwater flow conditions associated with the MW-52 area system and the Northrop IRM. The simulated pathways for the particles released in the refined model layers 1, 3, 4, and 6, corresponding to the shallow, intermediate, deep, and very deep VCM impact, respectively, are presented on Figures A.3.6, A.3.7, A.3.8, and A.3.9, respectively. The particle pathways demonstrate that the MW-52 area system provides hydraulic containment of the shallow (Figure A.3.6), intermediate (Figure A.3.7), and deep (Figure A.3.8) VCM impact. The complete hydraulic containment of the VCM impact in the very deep zone is not achieved. As presented on

Figure A.3.9, particles released at the southern boundary of the very deep VCM impact move southward beyond the MW-52 area system and are captured by GP-1. As described above, the purpose of the MW-52 area system for Alternative 3A is to provide VCM mass removal, not necessarily to provide complete containment of the VCM subplume.

VCM migration simulations were conducted for Alternative 3A to evaluate the duration of pumping from the MW-52 area system necessary to prevent the occurrence of VCM concentrations at GP-1 that exceed $8.3 \mu\text{g/L}$. Two VCM migration simulations were conducted. The first VCM migration simulation was conducted under the influence of pumping both the MW-52 area system and Northrop IRM for a duration of 7.5 years, after which the VCM migration simulation was continued to the end of 80 years under the influence of the Northrop IRM pumping only. The second VCM migration simulation was conducted under the influence of pumping both the MW-52 area system and Northrop IRM for a duration of 5 years, after which the VCM migration simulation was continued to the end of 80 years under the influence of the Northrop IRM pumping only. The two VCM migration simulations were conducted for Alternative 3A using the TVD solution method only. The mass balance error remained below 0.025 percent for both simulations. The simulated VCM concentration profiles at SPPW-1, SPPW-2, SPPW-3, and GP-1 over 80 years are presented on Figures A.3.10 and A.3.11 for the 7.5-year and 5-year VCM Subplume Containment System pumping durations, respectively. Relatively insignificant simulated VCM concentrations result at the Northrop IRM extraction wells ONCT-1, ONCT-2, and ONCT-3 (i.e., $<1 \mu\text{g/L}$).

For the 7.5-year MW-52 area system pumping duration, the simulated VCM concentration at GP-1 does not exceed a concentration of $5 \mu\text{g/L}$ ($4.7 \mu\text{g/L}$) and decreases to approximately $1 \mu\text{g/L}$ at the end of the 80 year simulation. For the 5-year MW-52 area system pumping duration, the simulated VCM concentration at GP-1 slightly exceeds a concentration of $5 \mu\text{g/L}$ ($5.2 \mu\text{g/L}$) and decreases to approximately $2 \mu\text{g/L}$ at the end of the 80 year simulation.

3.4 ALTERNATIVE 3B: MW-52 AREA SYSTEM TO ACHIEVE ARARs

Alternative 3B involves pumping from the MW-52 area system to completely contain VCM within the MW-52 area and reduce VCM concentrations to below the VCM MCL of $2 \mu\text{g/L}$. For Alternative 3B, the pumping from the VCM Subplume Containment System is to prevent VCM concentrations from migrating beyond the MW-52 area system at a level greater than $2 \mu\text{g/L}$. The MW-52 area system extraction well layout described in Section 3.3 for Alternative 3A was applied for Alternative 3B. The particle

tracking simulations described in Section 3.3 for Alternative 3A demonstrate that the MW-52 area system pumping applied for Alternative 3A does not provide complete hydraulic containment of the entire VCM impact. For Alternative 3B, it was necessary to increase the pumping rates at SPPW-2 and SPPW-3 to 250 gpm to prevent VCM migration beyond the MW-52 area system. The pumping rate at SPPW-1 remained at 500 gpm. The discharge of the treated groundwater from the MW-52 area system was simulated at the same locations applied in Alternative 3A. The pumping and discharge rates for Alternative 3B associated with the MW-52 area system and the Northrop IRM as applied in the refined model are presented in Table A.3.4.

The migration of VCM under steady-state groundwater flow conditions resulting from the Alternative 3B MW-52 area system pumping and the Northrop IRM pumping was simulated for an 80-year time period. The VCM migration simulation was conducted using both the TVD and MOC solution methods for Alternative 3B. The simulated VCM concentration profiles at SPPW-1, SPPW-2, SPPW-3, and GP-1 over the 80-year time period determined using both the MOC and TVD methods are presented on Figure A.3.12. Relatively insignificant simulated VCM concentrations result at the Northrop IRM extraction wells ONCT-1, ONCT-2, and ONCT-3 (i.e., $<1 \mu\text{g/L}$). The simulated VCM concentration profiles resulting from the TVD method closely follow the simulated VCM concentration profiles resulting from the MOC method, although the TVD VCM profiles lie slightly below the MOC VCM profiles. The jaggedness in the MOC VCM profiles is a typical trait of the MOC method and results from the frequent redistribution of particles used in the particle tracking algorithm applied in the MOC solution. The mass balance error for the MOC solution remained below 2 percent for the entire simulation. The mass balance errors for the MOC solution demonstrate that the simulation suffered from some limited mass conservation difficulties, as is often the case for the MOC method. The mass balance error for the entire TVD solution was less than 0.005 percent indicating that an acceptable mass balance was achieved with this solution technique. Despite the mass balance problems associated with the MOC method, the close agreement between the TVD and the MOC VCM profiles at each extraction well demonstrates that the TVD finite-difference solution provides a reasonable prediction of the VCM migration that was not significantly impacted by numerical dispersion. The simulated VCM concentration profiles demonstrate that the VCM concentrations are reduced to the VCM MCL concentration of $2 \mu\text{g/L}$ at approximately 3.5 years, 14 years, and 27 years at SPPW-1, SPPW-2, and SPPW-3, respectively. No significant VCM concentrations result at GP-1.

The VCM concentration distributions simulated at the end of years 10, 20, and 30 in refined model layers 1 to 12 are presented on Figures A.3.13 to A.3.24. At the end of year 30, VCM concentrations are reduced to below the MCL in the refined model

layers 1, 2, 3, 4, 5, 6, 7, and 12. Maximum VCM concentrations of approximately 5 µg/L, 15 µg/L, 5 µg/L, and 5 µg/L remain in refined model layers 8, 9, 10, and 11 at the end of year 30. The areas in the refined model layers 8, 9, 10, and 11 where VCM concentrations remain above the MCL at the end of year 30 are isolated to the location of SPPW-3 (see Figures A.3.20, A.3.21, A.3.22, and A.3.23, respectively). The areas where VCM concentrations remain above the MCL are considered minimal and, as demonstrated by the VCM concentration profile for GP-1 presented on Figure A.3.12, insignificant VCM concentrations reach the Northrop IRM extraction wells. Therefore, the MW-52 area system pumping simulated for Alternative 3B provides containment of the VCM impact in the MW-52 area and essentially reduces VCM concentrations to below the VCM MCL of 2 µg/L within approximately 30 years.

4.0 REFERENCES

- CRA, 1999, Draft Remedial Investigation Report, Operable Unit-3, Hooker/Ruco Site, Hicksville, New York, January.
- Environmental Simulations, Inc., 1996, Groundwater Vista, Advanced Model Design & Analysis, Herndon, Virginia.
- G&M, 1997, Groundwater Flow Model, Northrop Grumman Corporation, Bethpage, New York, Melville, New York, October.
- Gelhar, L.W., C. Welty, and K.W. Rehfeldt, 1992, A Critical Review of Data on Field-Scale Dispersion in Aquifers, Water Resources Research, Vol. 28, No. 7, pp. 1955-1974.
- Harbaugh, A.W. and M.G. McDonald, 1996, User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model, USGS Open-File Report 96-485.
- McDonald, M.G. and A.W. Harbough, 1988, A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, United States Geological Survey, TecA. Water-Resources Inv., Bk. 6, Chap. A1.
- Salhota, A.M, P. Minehart, S.S. Sharp-Hansen, T. Allison, R. Jones, and W.B. Mills, 1993, Multimedia Exposure Assessment Model (MULTIMED) for Evaluating the Land Disposal of Wastes, U.S. Environmental Protection Agency, Athens, Georgia.
- Zheng, C., 1991, PATH3D: A Ground-Water and Travel-Time Simulator, S.S. Papadopoulos & Associates, Inc., Bethesda, MD.
- Zheng, C., 1992, MT3D: A Modular Three-Dimensional Multispecies Transport Model, Version 1.5, S.S. Papadopoulos & Associates, Inc., Bethesda, MD, February.
- Zheng, C. and G.D. Bennett, 1995, Applied Contaminant Transport Modeling, Theory and Practice, Van Nostrand Reinhold, New York, NY.
- Zheng, C. and P.P. Wang, 1998, MT3DMS: A Modular Three-Dimensional Multispecies Transport Model, developed for the US Army Corps of Engineers, June.

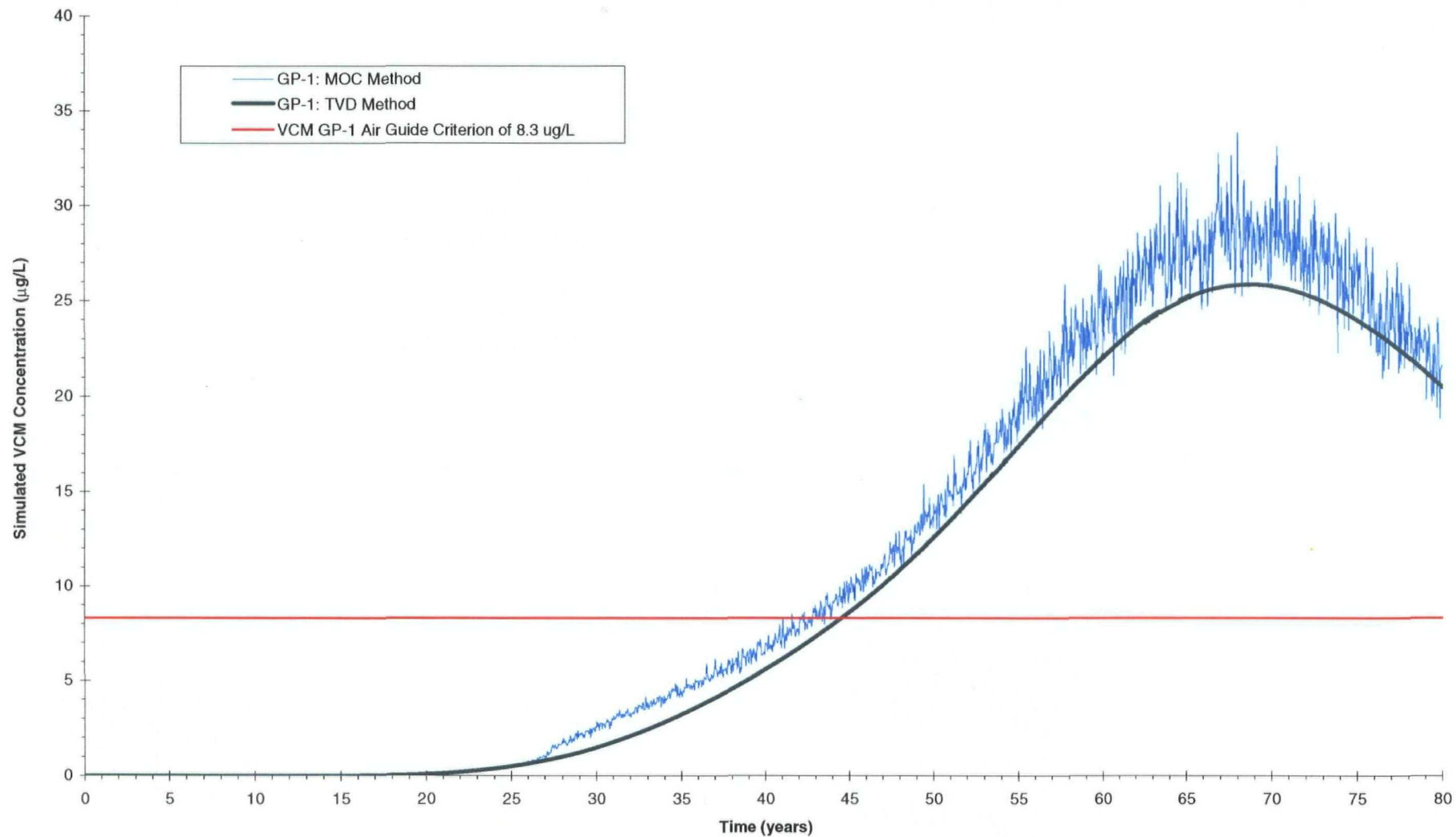
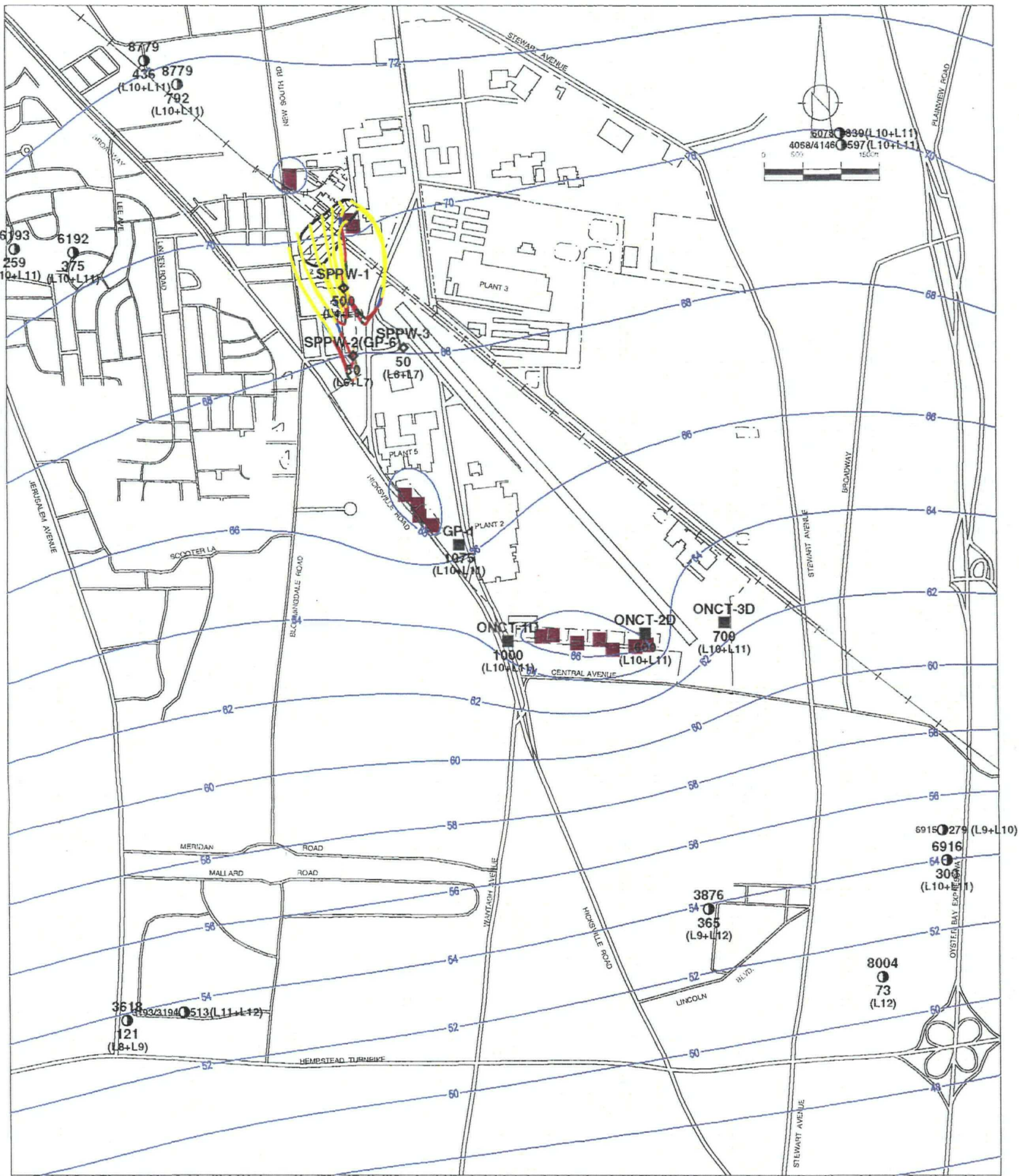


figure A.3.5
 ALTERNATIVE 2: ENHANCED NORTHROP IRM
 SIMULATED VCM CONCENTRATION PROFILE AT GP-1 UNDER NORTHROP IRM
 OU-3 FEASIBILITY STUDY
 Hooker/Ruco Site, Hicksville, New York

CRA



Legend

- Active sump/recharge basin location.
- GP-1
- Northrop pumping well location and pumping rate (gpm) from refined model layers ().
- 1075 (L10+L11)
- 6192
- Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- 375 (L10+L11)
- SPPW-1
- ◆ VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 500 (L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 1 of refined model (ft amsl).
- Particle pathway in revised model layer 1.
- Particle pathway in revised model layer 2.
- Particle pathway in revised model layer 3.
- Particle pathway in revised model layer 4.
- Particle pathway in revised model layer 5.
- Particle pathway in revised model layer 6.
- Particle pathway in revised model layer 7.

Note: Particles were released in refined model layer 1.

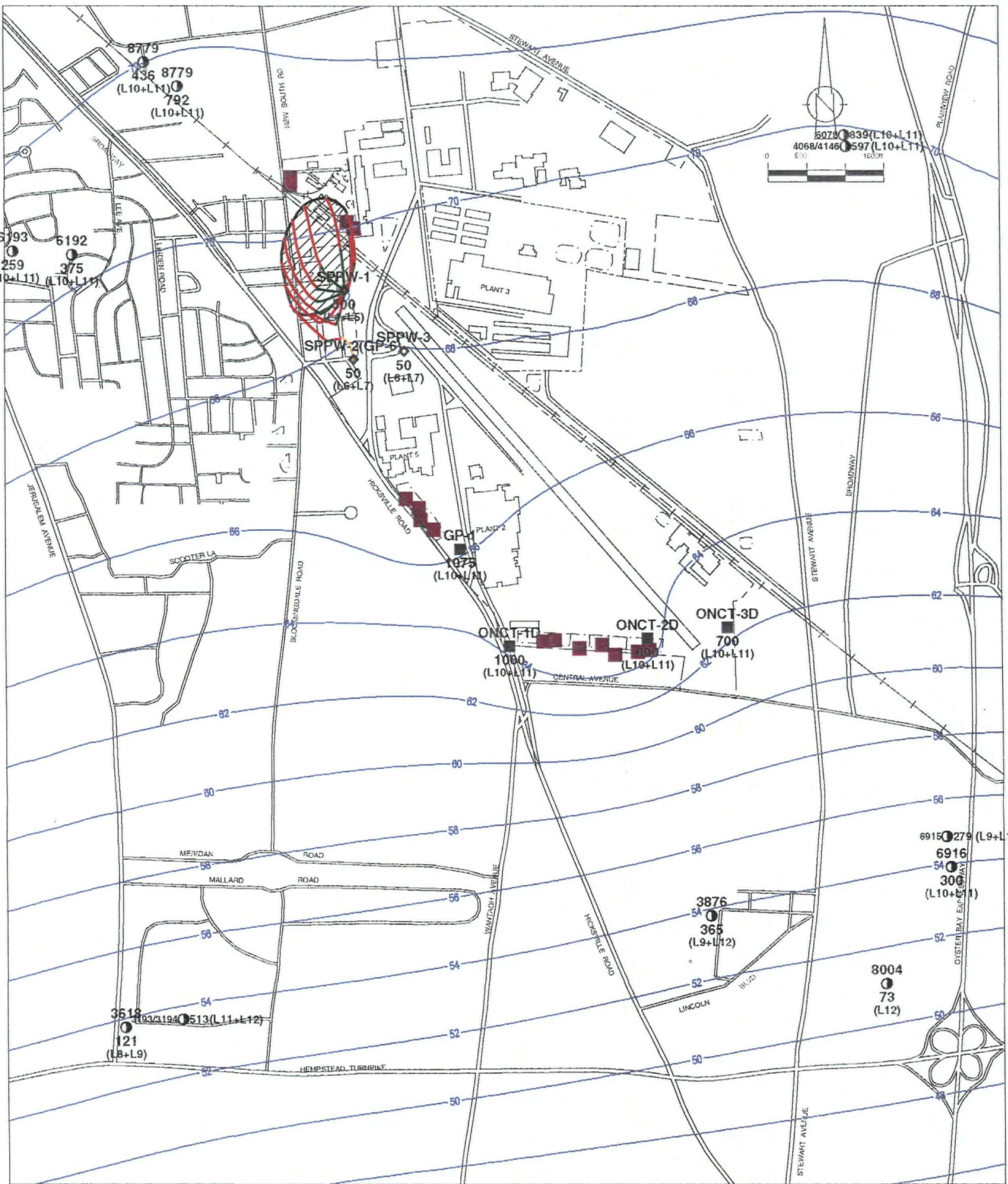


Shallow VCM presence specified in refined model layers 1 and 2

figure A.3.6
ALTERNATIVE 3A
MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION
HYDRAULIC CONTAINMENT OF SHALLOW VCM IMPACT
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

CRA

06883-00(018)GN-W-HYD (n:\hegl\6883b\lts\mod\52_vcmshl.srf) MAR 2/99



Legend

- Active sump/recharge basin location
- GP-1
1075
(L10+L11)
6192
375
(L10+L11)
SPPW-1
500
(L4+L5)
- Northrop pumping well location and pumping rate (gpm) from refined model layers ().
- Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 68 — Simulated steady-state hydraulic head in layer 3 of refined model (ft amsl).
- Particle pathway in revised model layer 3.
- Particle pathway in revised model layer 4.
- Particle pathway in revised model layer 5.
- Particle pathway in revised model layer 6.
- Particle pathway in revised model layer 7.

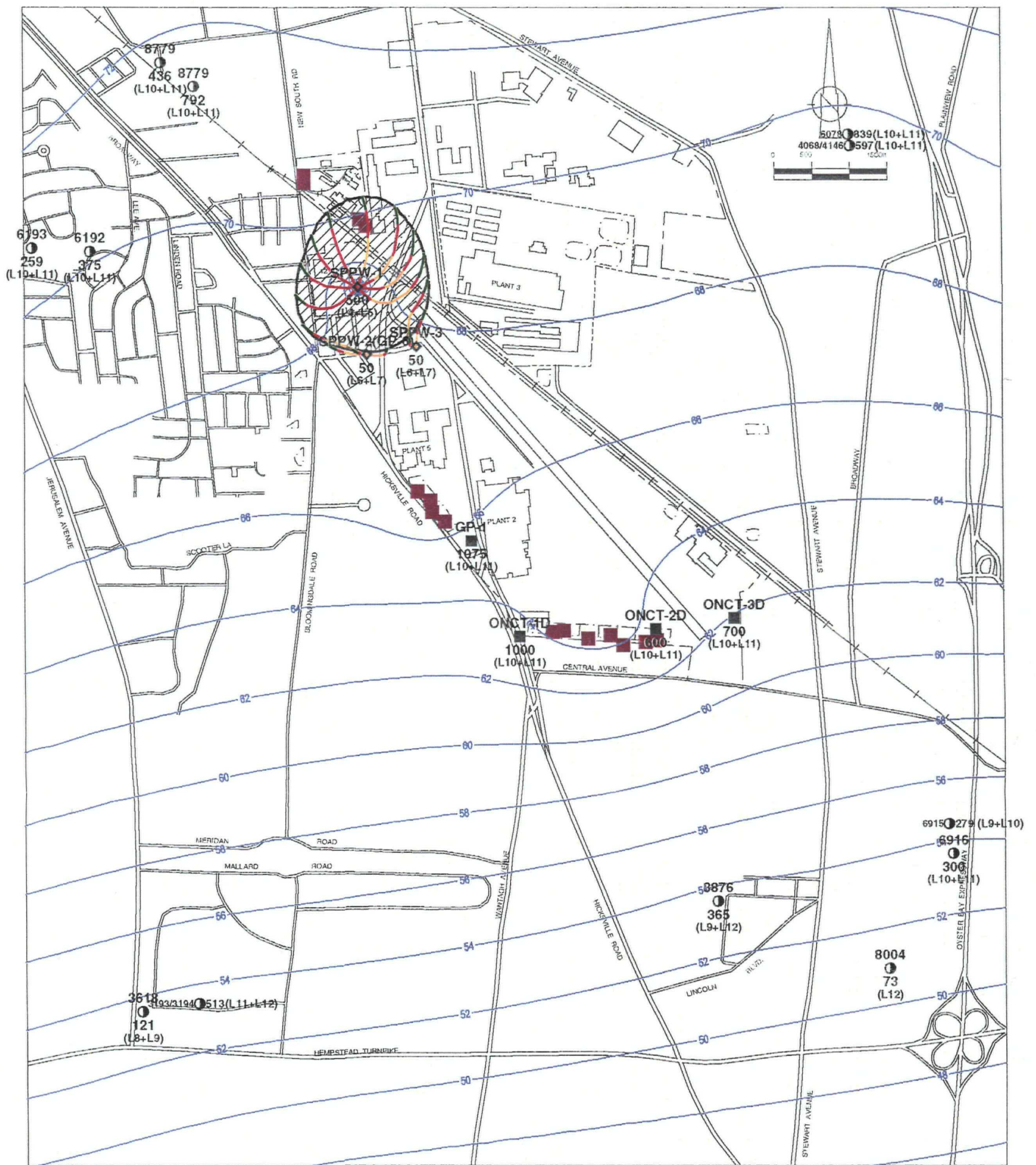
Note: Particles were released in refined model layer 3.

Intermediate VCM presence specified in refined model layer 3.

figure A.3.7
ALTERNATIVE 3A
MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION
HYDRAULIC CONTAINMENT OF INTERMEDIATE VCM IMPACT
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

CRA

06883-00(018)GN-W-HYD (n:\hgl6883b\lfs\mod52_vcmint.srf) MAR 2/99



Legend

- Active sump/recharge basin location.
- GP-1
1075
(L10+L11)
6192
375
(L10+L11)
SPPW-1
500
(L4+L5)
- Northrop pumping well location and pumping rate (gpm) from refined model layers ().
- Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- ◇ VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 68 — Simulated steady-state hydraulic head in layer 4 of refined model (ft amsl).
- Particle pathway in revised model layer 4
- Particle pathway in revised model layer 5
- Particle pathway in revised model layer 6
- Particle pathway in revised model layer 7

Note: Particles were released in refined model layer 4.



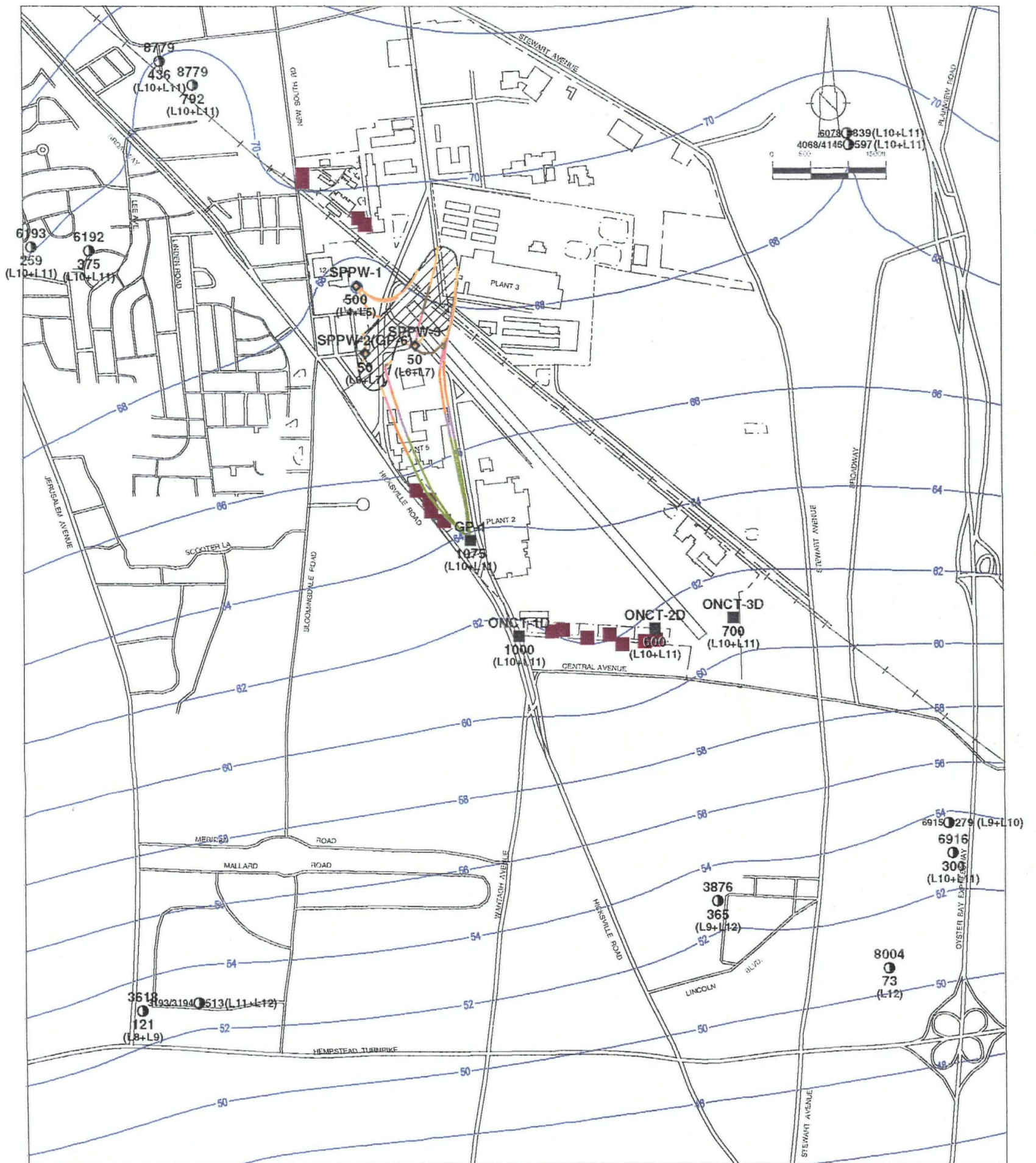
Deep VCM presence specified in refined model layers 4 and 5.

figure A.3.8
ALTERNATIVE 3A

MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION
HYDRAULIC CONTAINMENT OF DEEP VCM IMPACT
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

CRA

06883-00(018)GN-W-HYD (n:\hegl\6883b\fs\mod52_vcmdeep.srf) MAR 2/99



Legend

- Active sump/recharge basin location
- GP-1
- Northrop pumping well location and pumping rate (gpm) from refined model layers ()
- 1075 (L10+L11)
- Municipal pumping well location and pumping rate (gpm) from refined model layers ()
- 6192 (L10+L11)
- 375 (L10+L11)
- SPPW-1
- ◆ VCM System pumping well location and pumping rate (gpm) from refined model layers ()
- 500 (L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 6 of refined model (ft amsl)
- Particle pathway in revised model layer 6
- Particle pathway in revised model layer 7
- Particle pathway in revised model layer 8
- Particle pathway in revised model layer 9
- Particle pathway in revised model layer 10
- Particle pathway in revised model layer 11

Note: Particles were released in refined model layer 6.

Very deep VCM presence specified in refined model layers 6, 7, 8, and 9.

figure A.3.9
ALTERNATIVE 3A
MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION
HYDRAULIC CONTAINMENT OF VERY DEEP VCM IMPACT
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

CRA

06883-00(018)GN-W-HYD (n:\hegl\6883b\mod52_vcmvdeep.srf) MAR 2/99

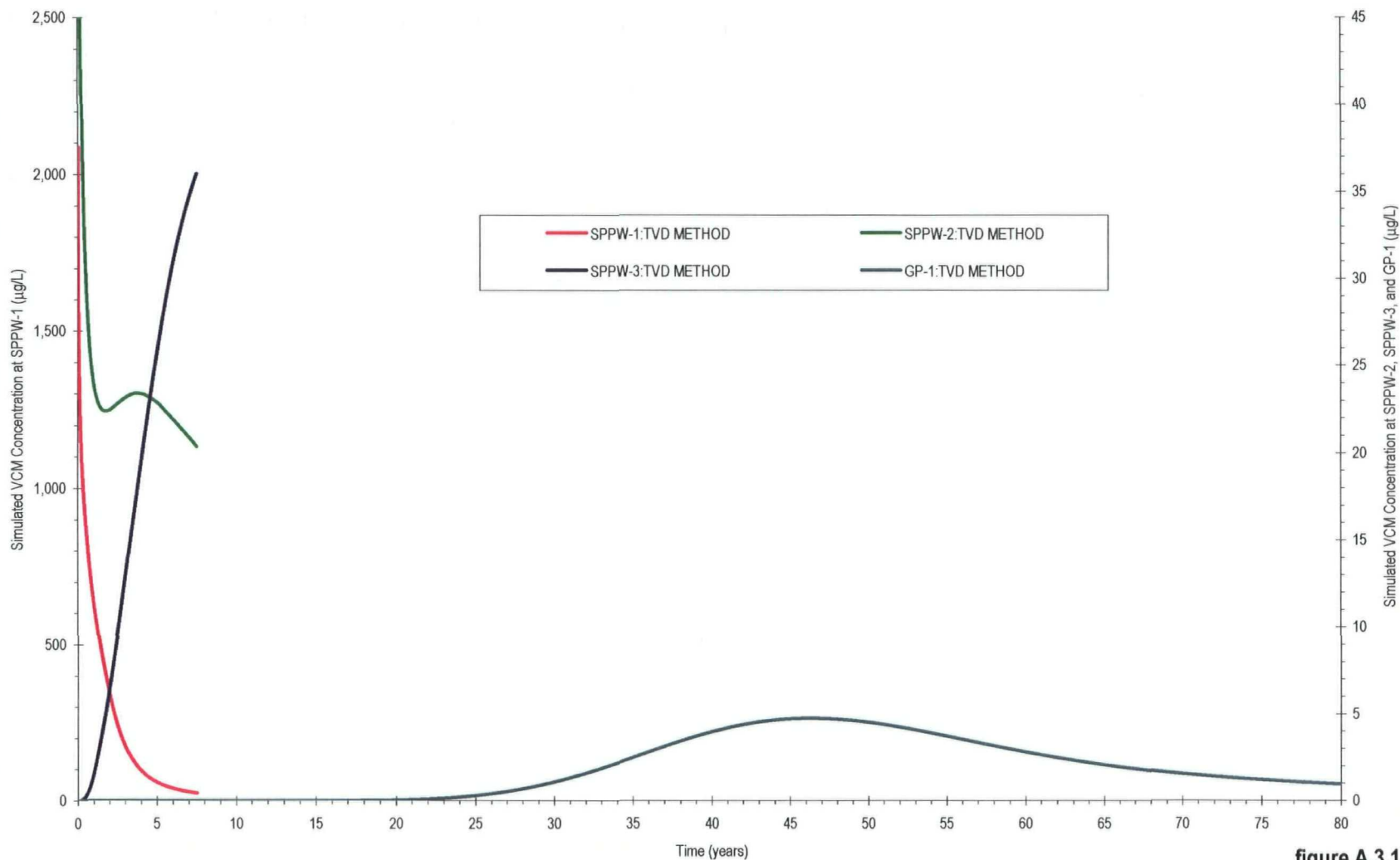


figure A.3.10

ALTERNATIVE 3A

7.5-YEAR PUMPING OF MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION

SIMULATED VCM CONCENTRATION PROFILES

OU-3 FEASIBILITY STUDY

Hooker/Ruco Site, Hicksville, New York

CRA

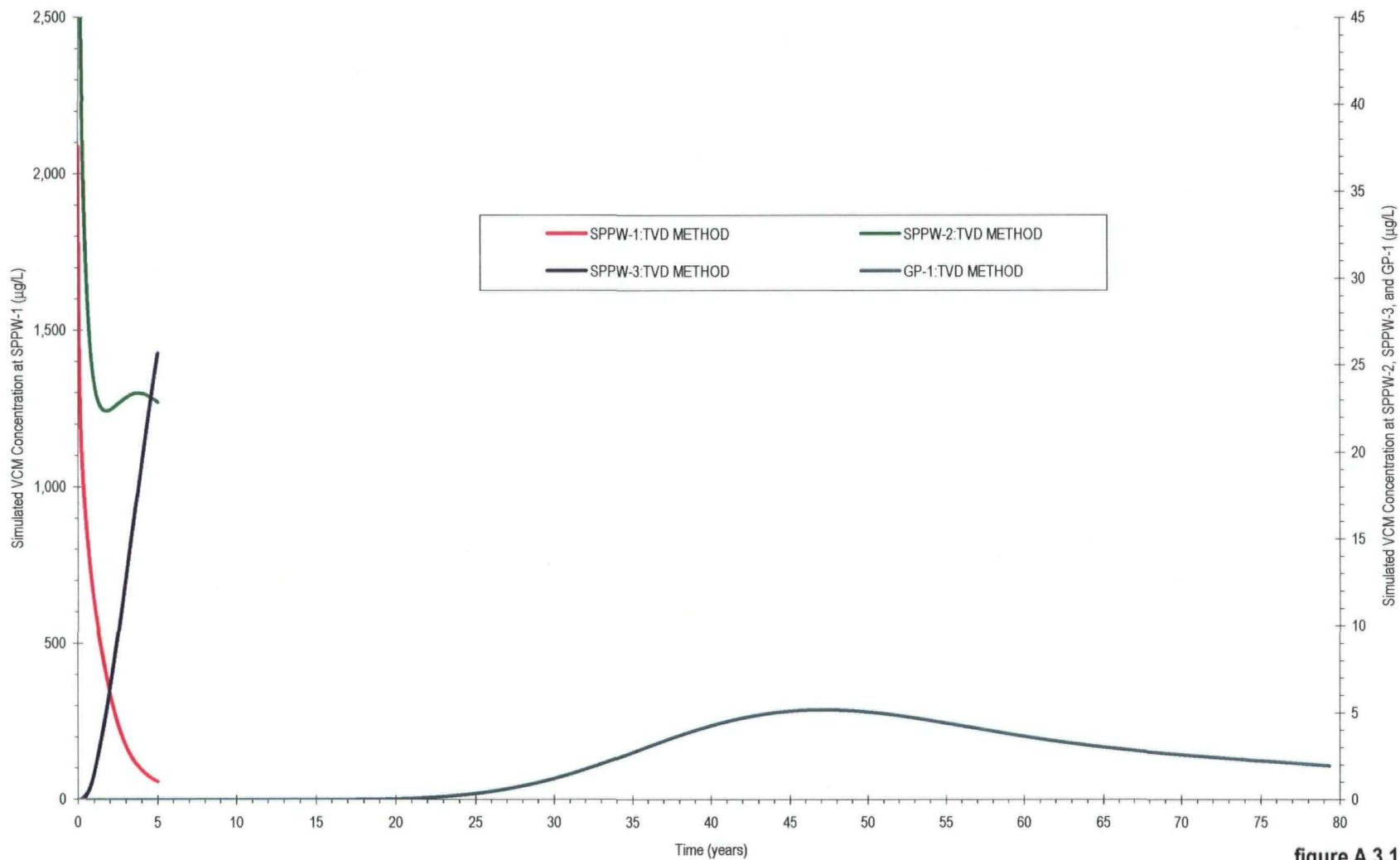


figure A.3.11

ALTERNATIVE 3A

5-YEAR PUMPING OF MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION

SIMULATED VCM CONCENTRATION PROFILES

OU-3 FEASIBILITY STUDY

Hooker/Ruco Site, Hicksville, New York

CRA

06883-00(018)GN-W-HYD (n:\hegl6883b\fs\mod\tmpl52vcd7d&e.xls) MAR 2/99

400220

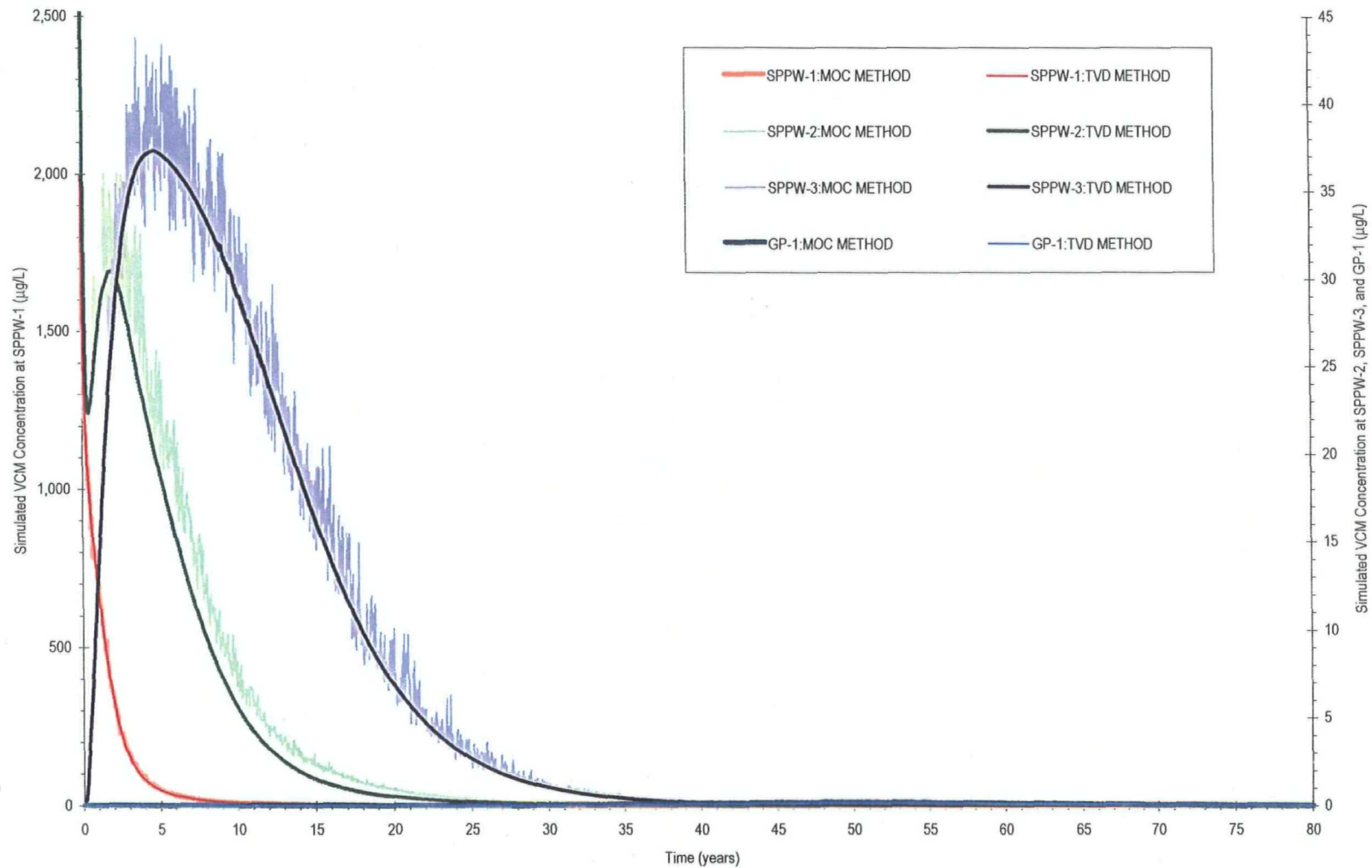


figure A.3.12
 ALTERNATIVE 3B
 MW-52 AREA SYSTEM TO ACHIEVE ARARs
 SIMULATED VCM CONCENTRATION PROFILES
 OU-3 FEASIBILITY STUDY
 Hooker/Ruco Site, Hicksville, New York

CRA



Legend

- Active sump/recharge basin location.
- GP-1
1075
(L10+L11)
Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- 6192
375
(L10+L11)
Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- SPPW-1
500
(L4+L5)
VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 68 — Simulated steady-state hydraulic head in layer 1 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 1 of refined model (ug/L).
- 20 — 20-year simulated VCM concentrations in layer 1 of refined model (ug/L).
- 30 — 30-year simulated VCM concentrations in layer 1 of refined model (ug/L).

Note: VCM concentrations above 0.1 ug/L do not remain in layer 1 for years 20 or 30.

figure A.3.13
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 1
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
 - GP-1
 - Northrop pumping well location and pumping rate (gpm)
1075 (L10+L11)
 - Municipal pumping well location and pumping rate (gpm)
6192 (L10+L11)
375 (L10+L11)
 - SPPW-1
 - ◆ VCM System pumping well location and pumping rate (gpm)
500 (L4+L5)
 - 68 — Simulated steady-state hydraulic head in layer 2 of refined model (ft amsl).
 - 10 — 10-year simulated VCM concentrations in layer 2 of refined model (ug/L).
 - 10 — 20-year simulated VCM concentrations in layer 2 of refined model (ug/L).
 - 10 — 30-year simulated VCM concentrations in layer 2 of refined model (ug/L).
- Note: VCM concentrations above 0.1 ug/L do not remain in layer 2 for years 20 and 30.

figure A.3.14
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 2
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm) from refined model layers ().
- 1075
(L10+L11)
- 6192
● Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- 375
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 500
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 3 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 3 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 3 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 3 of refined model (ug/L).

Note: VCM concentrations above 0.1 ug/L do not remain in layer 3 for year 30.

figure A.3.15
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 3
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

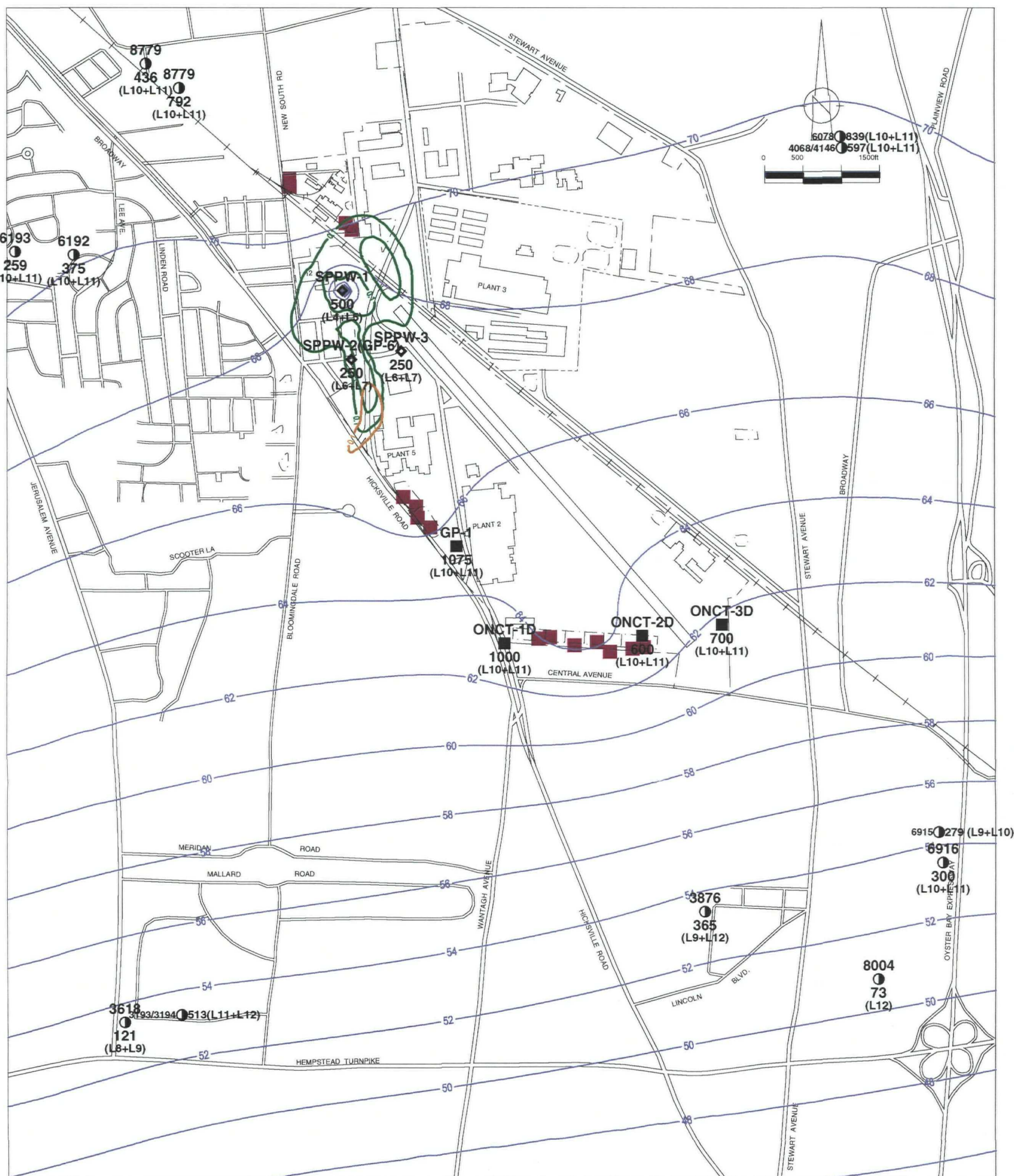
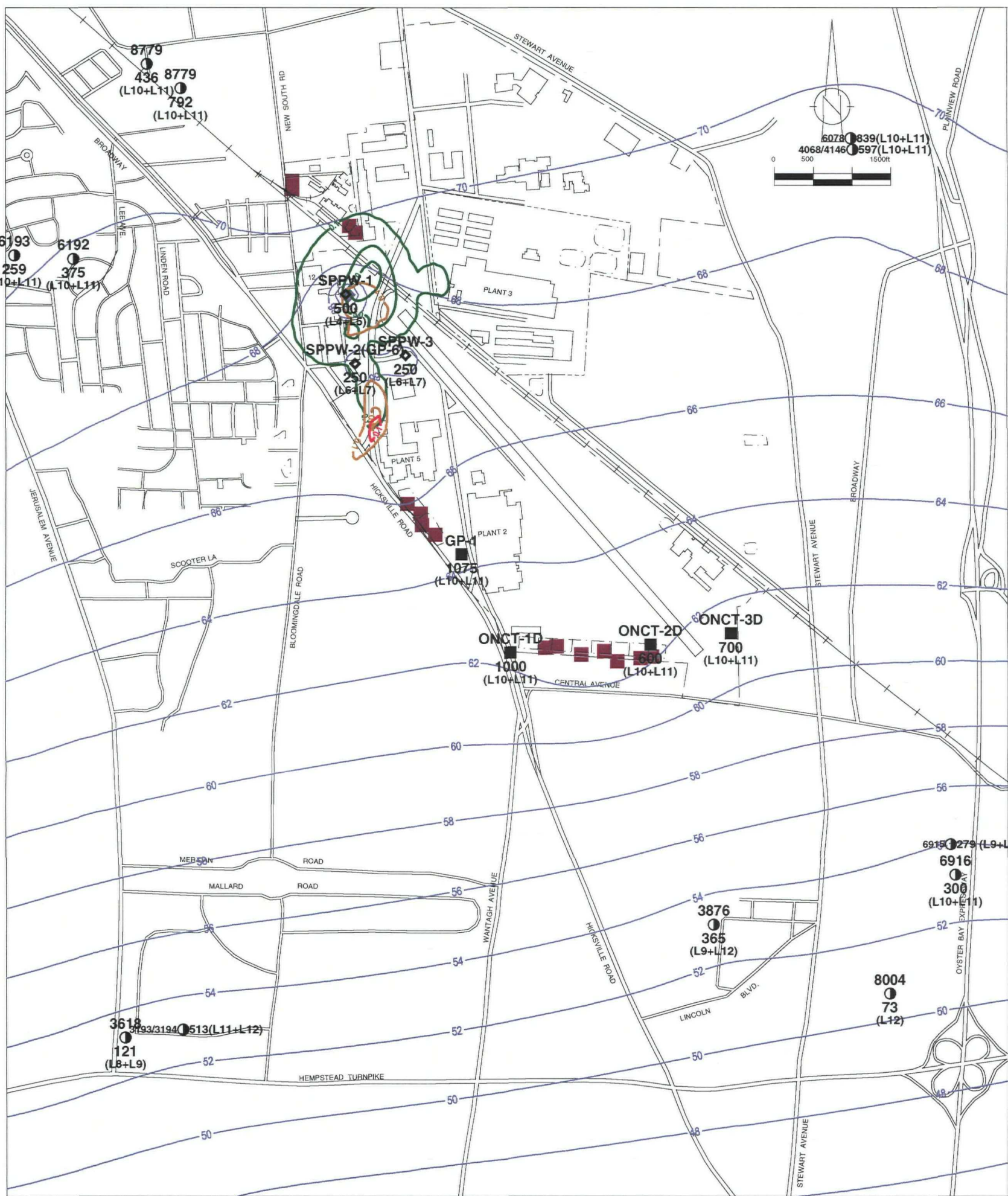


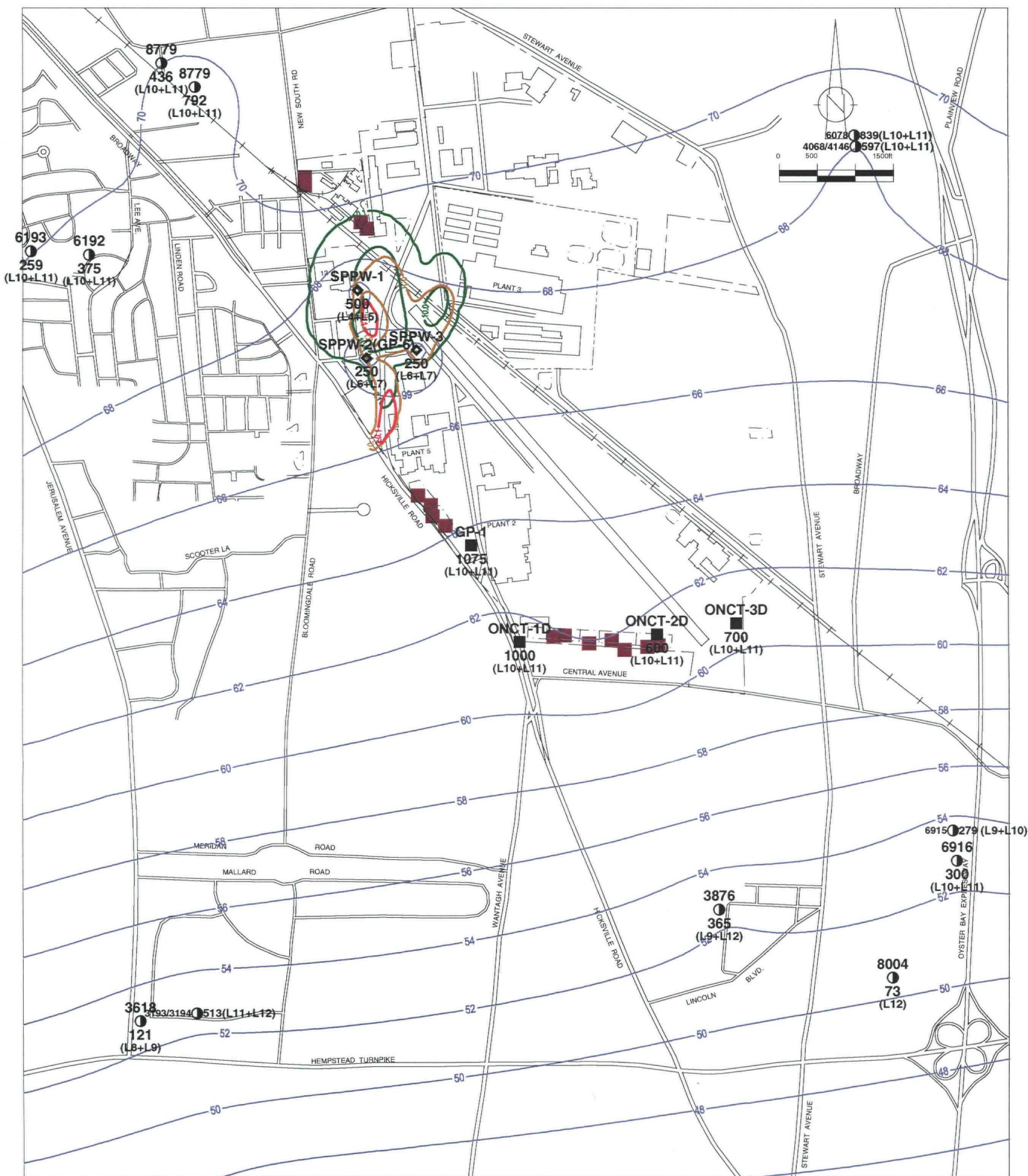
figure A.3.16
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 4
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075
(L10+L11)
- 6192
● Municipal pumping well location and pumping rate (gpm)
375
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 5 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 5 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 5 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 5 of refined model (ug/L).

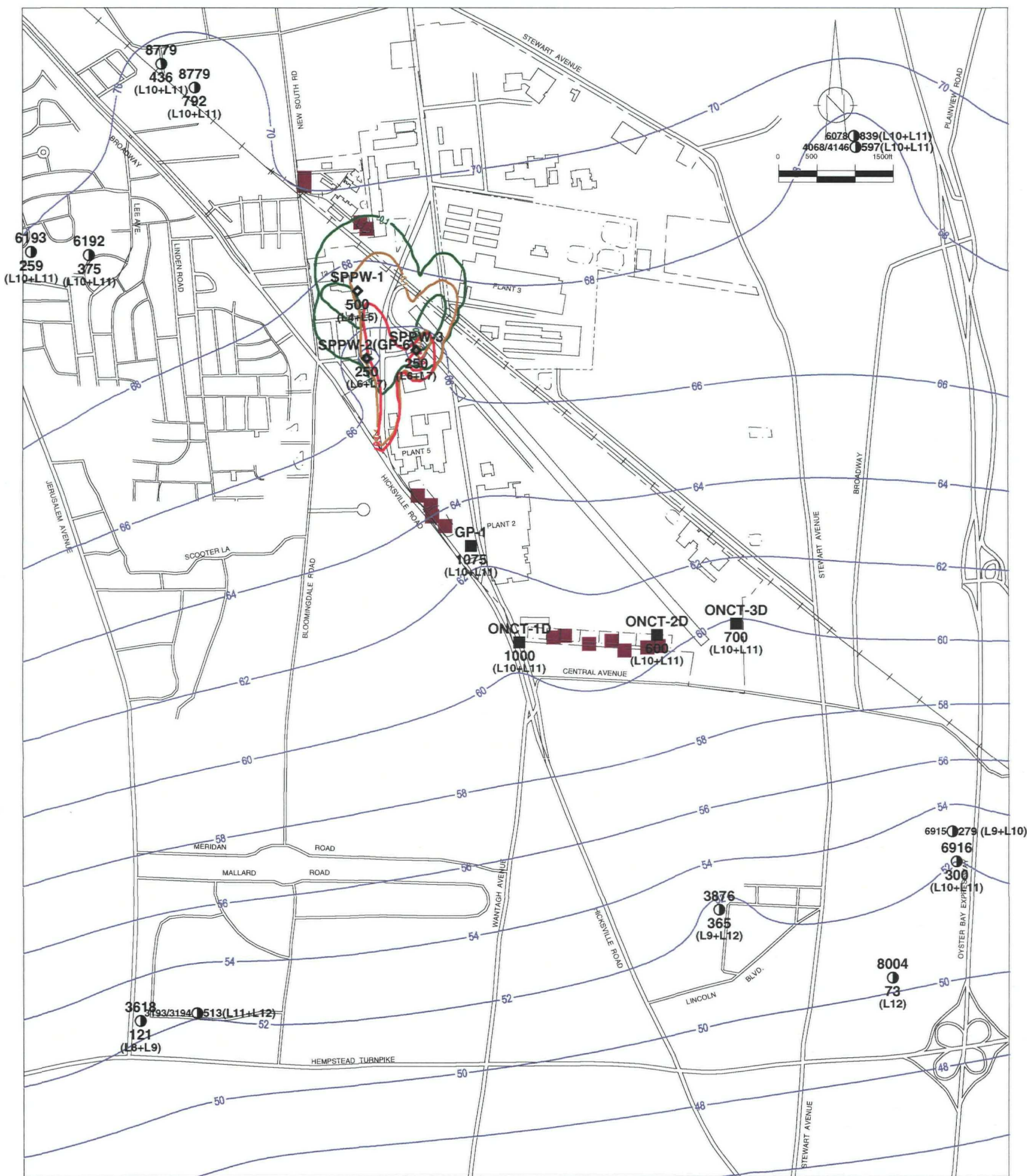
figure A.3.17
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 5
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075 (L10+L11)
- 6192
● Municipal pumping well location and pumping rate (gpm)
375 (L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500 (L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 6 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 6 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 6 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 6 of refined model (ug/L).

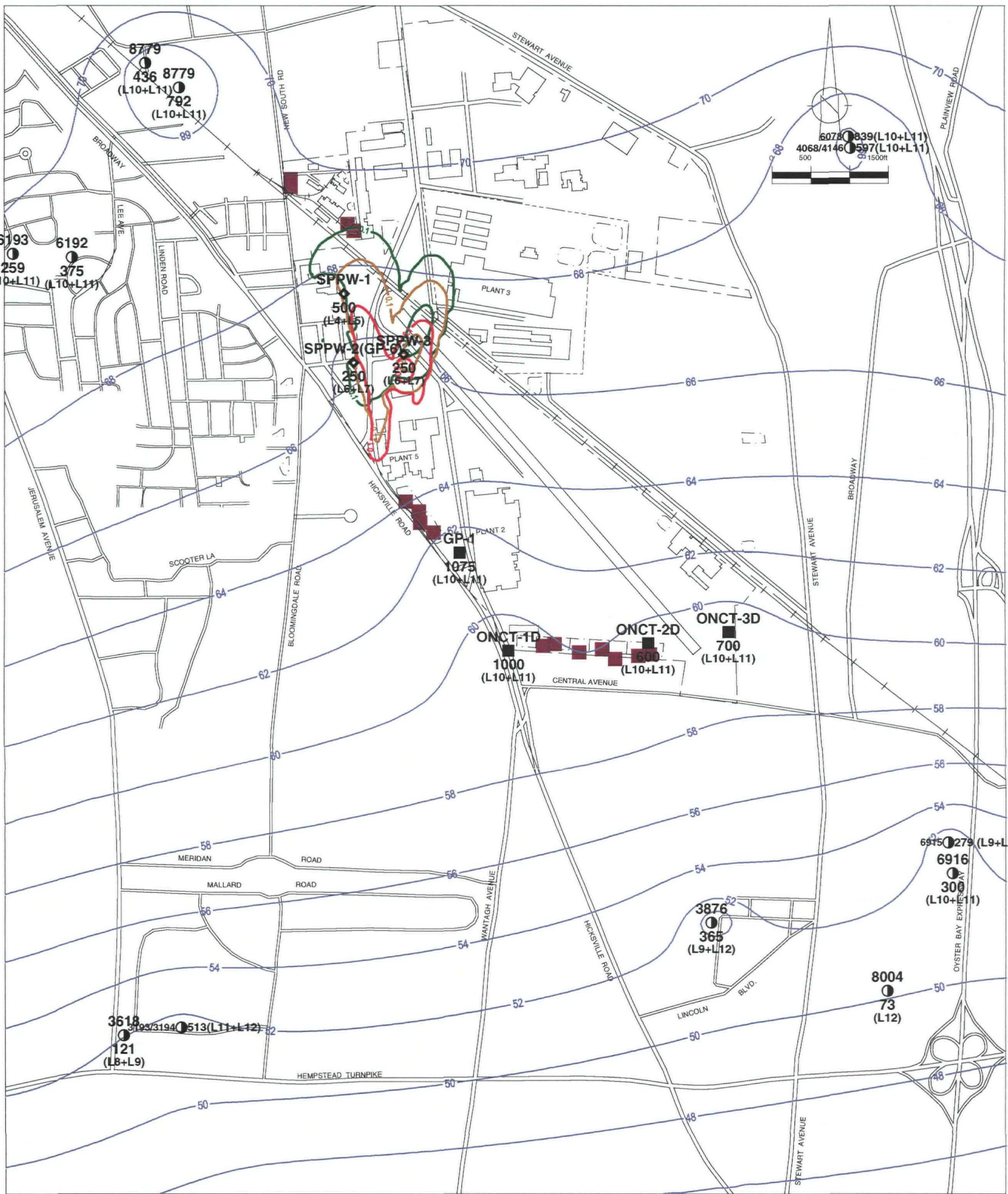
figure A.3.18
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 6
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075
(L10+L11)
- Municipal pumping well location and pumping rate (gpm)
6192
375
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 7 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 7 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 7 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 7 of refined model (ug/L).

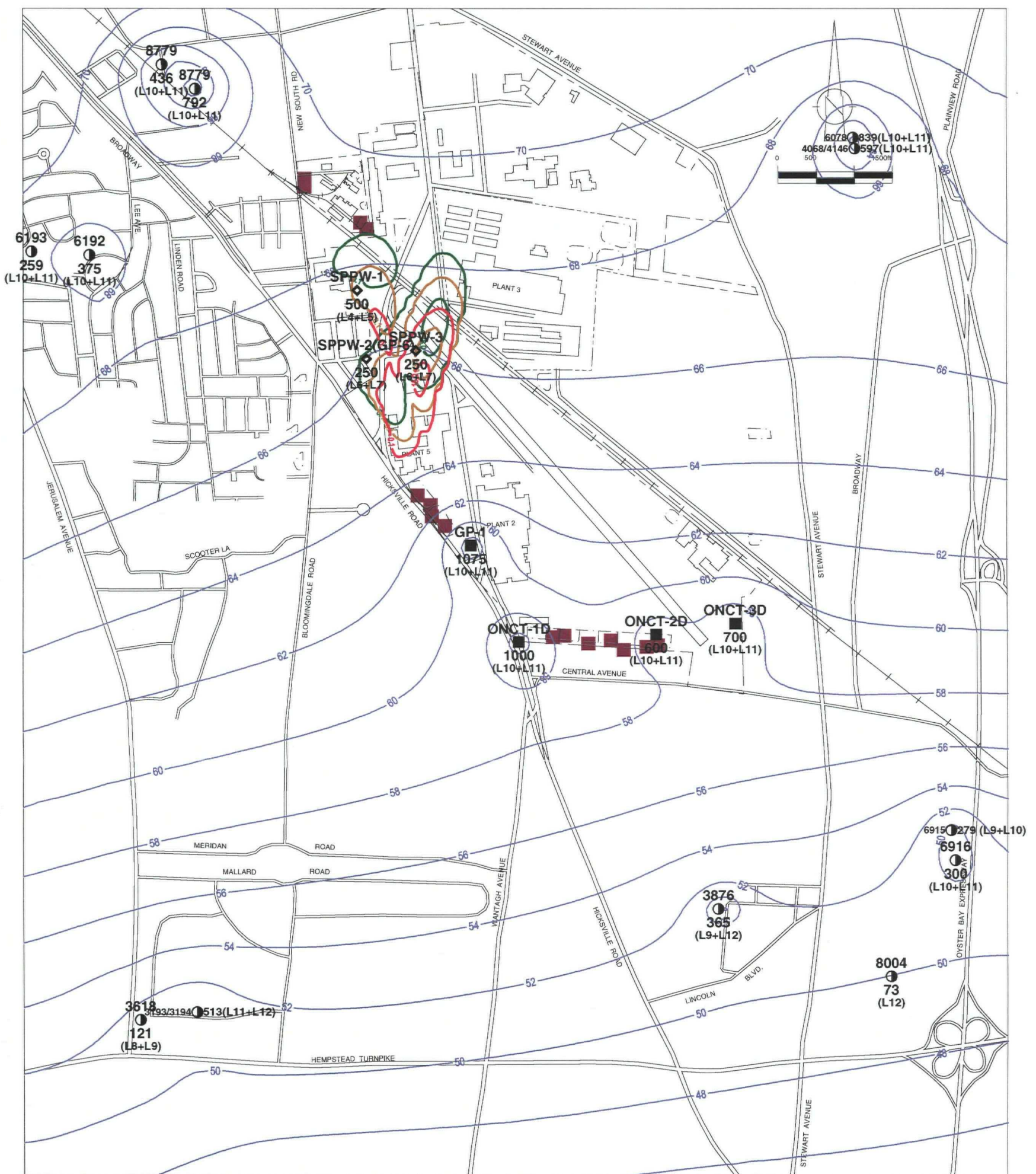
figure A.3.19
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 7
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075
(L10+L11)
- 6192
● Municipal pumping well location and pumping rate (gpm)
375
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 8 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 8 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 8 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 8 of refined model (ug/L).

figure A.3.20
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 8
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075
(L10+L11)
- Municipal pumping well location and pumping rate (gpm)
6192
375
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 9 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 9 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 9 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 9 of refined model (ug/L).

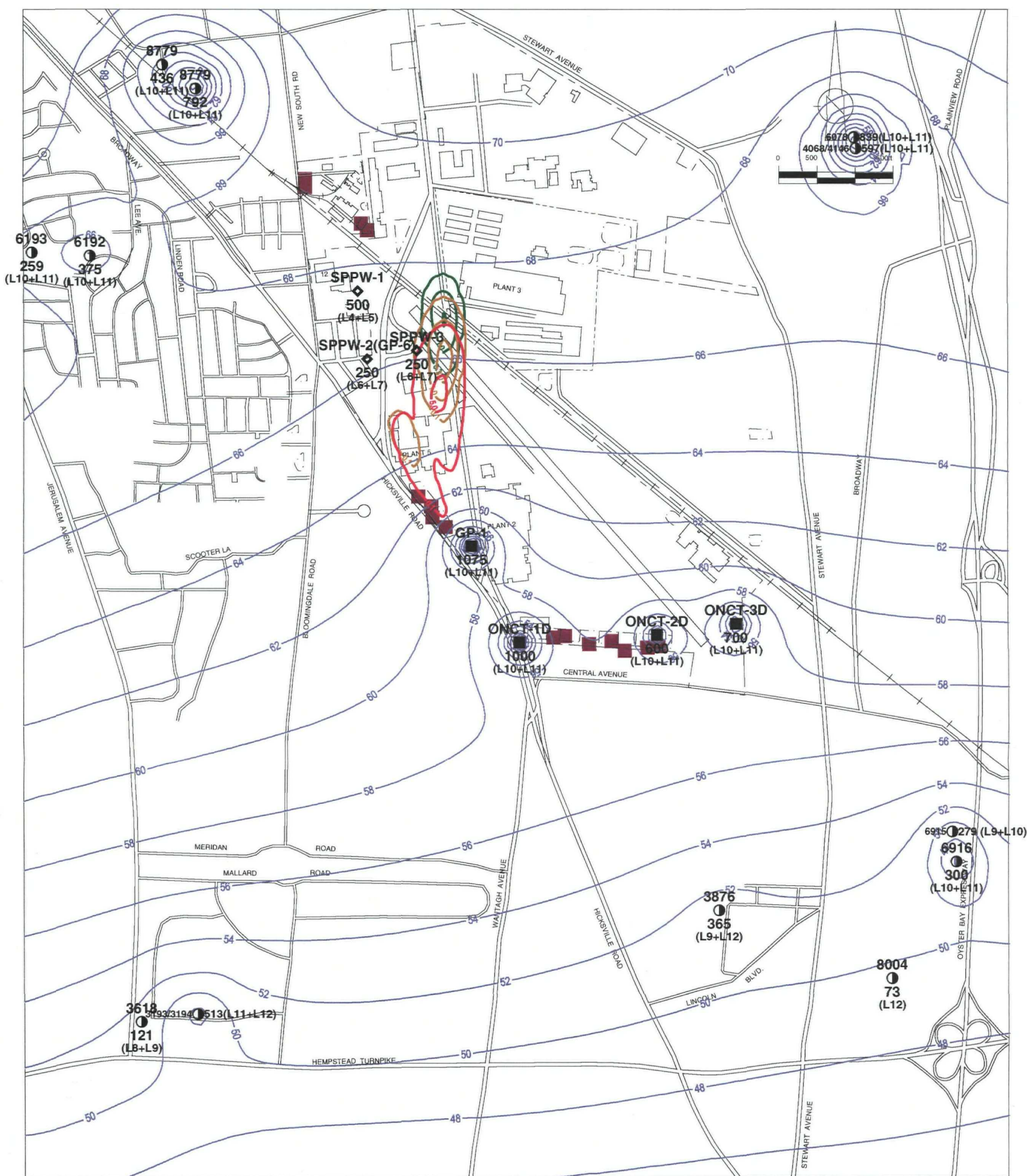
figure A.3.21
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 9
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
1075
(L10+L11)
● Northrop pumping well location and pumping rate (gpm) from refined model layers ().
- 6192
375
(L10+L11)
● Municipal pumping well location and pumping rate (gpm) from refined model layers ().
- SPPW-1
500
(L4+L5)
◆ VCM System pumping well location and pumping rate (gpm) from refined model layers ().
- 68 — Simulated steady-state hydraulic head in layer 10 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 10 of refined model (ug/L).
- 20 — 20-year simulated VCM concentrations in layer 10 of refined model (ug/L).
- 30 — 30-year simulated VCM concentrations in layer 10 of refined model (ug/L).

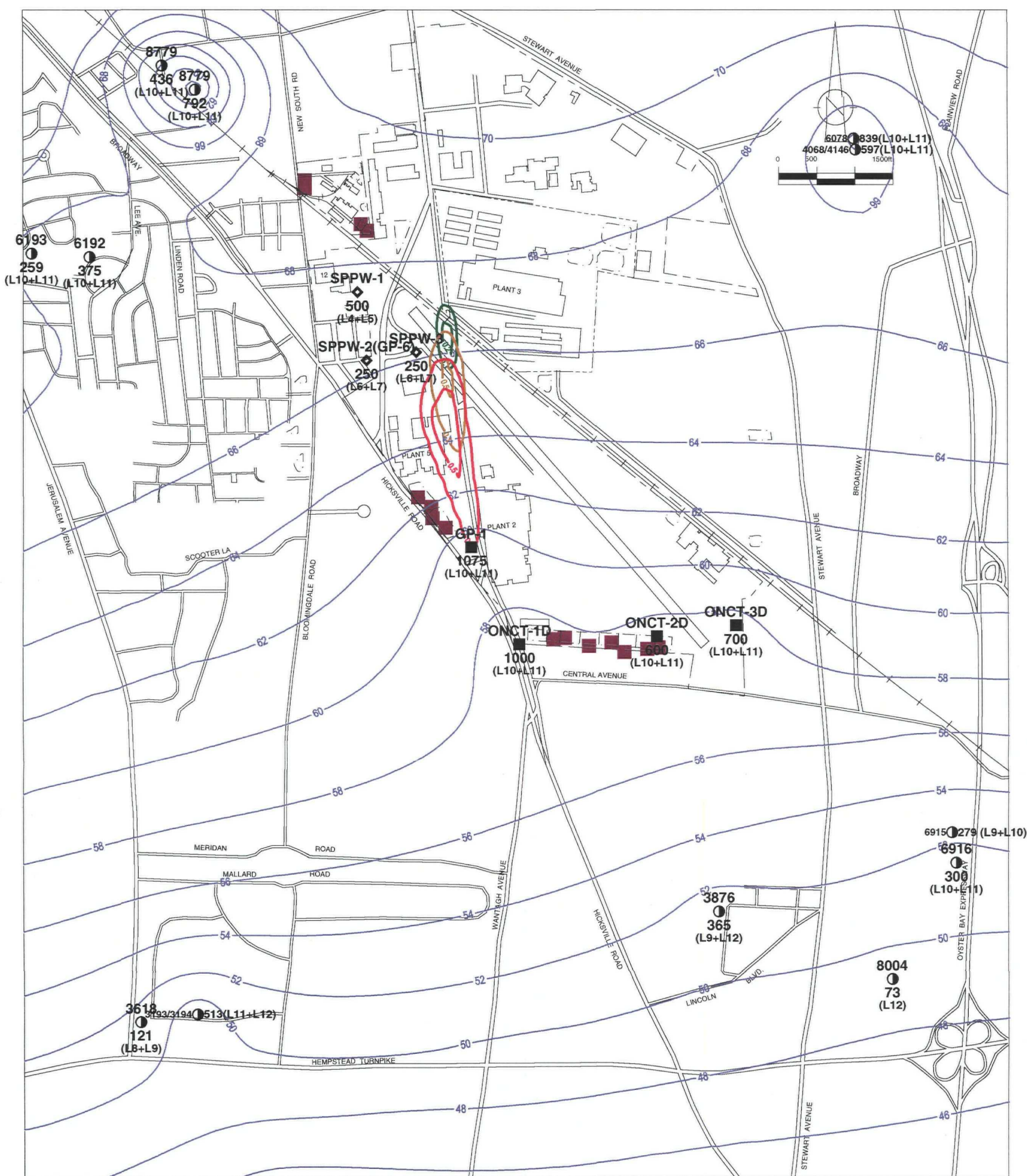
figure A.3.22
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 10
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075 from refined model layers ().
(L10+L11)
- GP-2
● Municipal pumping well location and pumping rate (gpm)
375 from refined model layers ().
(L10+L11)
- SPPW-1
◆ VCM System pumping well location and pump rate (gpm)
500 from refined model layers ().
(L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 11 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 11 of refined model (ug/L).
- 10 — 20-year simulated VCM concentrations in layer 11 of refined model (ug/L).
- 10 — 30-year simulated VCM concentrations in layer 11 of refined model (ug/L).

figure A.3.23
 ALTERNATIVE 3B
 MW-52 AREA SYSTEM TO ACHIEVE ARARs
 SIMULATED VCM CONCENTRATION IN LAYER 11
 OU-3 FEASIBILITY STUDY
 Hooker/Ruco Site, Hicksville, New York



Legend

- Active sump/recharge basin location.
- GP-1
■ Northrop pumping well location and pumping rate (gpm)
1075 from refined model layers ().
- 6192
● Municipal pumping well location and pumping rate (gpm)
375 from refined model layers ().
- (L10+L11)
- SPPW-1
◆ VCM System pumping well location and pumping rate (gpm)
500 from refined model layers ().
- (L4+L5)
- 68 — Simulated steady-state hydraulic head in layer 12 of refined model (ft amsl).
- 10 — 10-year simulated VCM concentrations in layer 12 of refined model (ug/L).
- 20 — 20-year simulated VCM concentrations in layer 12 of refined model (ug/L).
- 30 — 30-year simulated VCM concentrations in layer 12 of refined model (ug/L).

figure A.3.24
ALTERNATIVE 3B
MW-52 AREA SYSTEM TO ACHIEVE ARARs
SIMULATED VCM CONCENTRATION IN LAYER 12
OU-3 FEASIBILITY STUDY
Hooker/Ruco Site, Hicksville, New York

TABLE A.3.1

**NORTHROP IRM PUMPAGE AND DISCHARGE RATES
OU-3 FEASIBILITY STUDY
HOOKER/RUCO SITE, HICKSVILLE, NEW YORK**

Pumpage ⁽¹⁾

| Production/ Extraction Well | G&M Calibrated Model Cell (i,j,k) | Original Northrop IRM | | Current Northrop IRM Pumping Rate ⁽²⁾ (gpm) |
|-----------------------------------|---|--------------------------------------|--------------------------------------|--|
| | | Minimum IRM Pumping Rate (gpm) | Maximum IRM Pumping Rate (gpm) | |
| GP-1 | 53,29,7 | 1,075 | 1,075 | 1,075 |
| GP-2 | 43,30,7 | 0 | 0 | 0 |
| GP-3 | 48,30,7 | 0 | 0 | 0 |
| GP-4 | 50,29,5 | 0 | 0 | 0 |
| GP-5 | 37,27,5 | 0 | 0 | 0 |
| GP-6 | 35,22,5 | 0 | 0 | 0 |
| GP-8 | 26,30,5 | 0 | 0 | 0 |
| GP-9 | 28,32,9 | 0 | 0 | 0 |
| GP-10 | 27,35,5 | 0 | 0 | 0 |
| GP-11 | 29,28,6 | 250 | 1,018 | 0 |
| GP-13 | 22,34,7 | 189 | 608 | 0 |
| GP-14 | 22,34,6 | 0 | 0 | 0 |
| GP-15 | 26,40,6 | 0 | 0 | 0 |
| GP-16 | 17,42,5 | 250 | 918 | 0 |
| ONCT-1D | 62,32,7 | 1,000 | 1,000 | 1,000 |
| ONCT-2D | 63,44,7 | 600 | 600 | 600 |
| ONCT-3D | 63,51,7 | 700 | 700 | 700 |

Discharge ⁽¹⁾

| Discharge Basin | Number of G&M Model Cells and Location Where Discharge was Simulated ⁽³⁾ | Original Northrop IRM | | Current Northrop IRM Discharge Rate ⁽²⁾ (gpm) |
|--------------------|---|--|--|--|
| | | Minimum IRM Discharge Rate (gpm) | Maximum IRM Discharge Rate (gpm) | |
| Plant 3 Basins | 24, Northeast of Northrop Plant 3 | 500 | 2,300 | 0 ⁽⁴⁾ |
| Plant 5 Basins | 4, South of Northrop Plant 5 | 1,215 | 1,215 | 1,215 |
| Plant 12 Basins | 2, Southeast of Northrop Plant 12 | 0 | 0 | 0 |
| Southern Basins | 7, Southeast of Northrop Plant 2 | 2,231 | 2,231 | 2,231 |

Notes:

- (1) The Northrop IRM pumpage and discharge rates were reported in the G&M correspondence to NYDEC dated March 5, 1997.
- (2) The pumping and discharge rates associated with the current Northrop IRM were applied in the simulations conducted by OxyChem.
- (3) The discharge was applied in refined model layer 1.
- (4) The Plant 3 discharge was assumed to result from the pumping at GP-11, GP-13, and GP-16. Without these wells pumping in the current Northrop IRM, the Plant 3 discharge was assumed to be zero.

TABLE A.3.2

**ALTERNATIVE 2: NO FURTHER ACTION (WITH THE NORTHROP IRM)
PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL
OU-3 FEASIBILITY STUDY
HOOKER/RUCO SITE, HICKSVILLE, NEW YORK**

Pumpage ⁽¹⁾

| <i>Production/ Extraction Well</i> | <i>Current Northrop IRM Pumping Rate (gpm)</i> | <i>Refined Model Layer Where Pumping was Simulated ⁽²⁾</i> |
|--|--|---|
| GP-1 | 1,075 | 10 & 11 |
| ONCT-1D | 1,000 | 10 & 11 |
| ONCT-2D | 600 | 10 & 11 |
| ONCT-3D | 700 | 10 & 11 |

Discharge ⁽¹⁾

| <i>Discharge Basin</i> | <i>Number of Refined Model Cells and Location Where Discharge was Simulated ⁽³⁾</i> | <i>Current Northrop IRM Discharge Rate (gpm)</i> |
|----------------------------|--|--|
| Plant 5 Basins | 39, South of Northrop Plant 5 | 1,215 |
| Southern Basins | 60, Southeast of Northrop Plant 2 | 2,231 |

Notes:

- (1) The current Northrop IRM pumpage and recharge rates are presented in Table A.3.1.
- (2) The extraction well pumpage was divided equally between the two refined model layers indicated.
- (3) The recharge was applied in the refined model layer 1.

TABLE A.3.3

**ALTERNATIVE 3A: MW-52 AREA SYSTEM TO ACHIEVE MASS REDUCTION
PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL
OU-3 FEASIBILITY STUDY
HOOKER/RUCO SITE, HICKSVILLE, NEW YORK**

Pumpage

| <i>Production/ Extraction Well</i> | <i>Pumping Rate (gpm)</i> | <i>Refined Model Layer Where Pumping was Simulated ⁽¹⁾</i> |
|--|-------------------------------|---|
| VCM Subplume Containment System | | |
| SPPW-1 | 500 | 4 & 5 |
| SPPW-2 | 50 | 6 & 7 |
| SPPW-3 | 50 | 6 & 7 |
| Nothrop IRM ⁽²⁾ | | |
| GP-1 | 1,075 | 10 & 11 |
| ONCT-1D | 100 | 10 & 11 |
| ONCT-2D | 600 | 10 & 11 |
| ONCT-3D | 700 | 10 & 11 |

Discharge

| <i>Discharge Basin</i> | <i>Number of Refined Model Cells and Location Where Discharge was Simulated ⁽³⁾</i> | <i>Discharge Rate (gpm)</i> |
|--|--|---------------------------------|
| VCM Subplume Containment System | | |
| Sump 1 | 2, Southeast corner of Hooker/Ruco Site | 50 |
| Sump 2 | 3, Southeast corner of Hooker/Ruco Site | 50 |
| New Sump | 9, Northwest corner of Hooker/Ruco Site | 500 |
| Nothrop IRM ⁽²⁾ | | |
| Plant 5 Basins | 39, South of Northrop Plant 5 | 1,215 |
| Southern Basins | 60, Southeast of Northrop Plant 2 | 2,231 |

Notes:

- (1) The extraction well pumpage was divided equally between the two refined model layers indicated.
- (2) The current Northrop IRM pumpage and recharge rates are presented in Table A.3.1.
- (3) The recharge was applied in the refined model layer 1.

TABLE A.3.4

**ALTERNATIVE 3B: VCM SUBPLUME CONTAINMENT SYSTEM TO REACH VCM MCLs
PUMPAGE AND DISCHARGE RATES IN THE REFINED MODEL
OU-3 FEASIBILITY STUDY
HOOKER/RUCO SITE, HICKSVILLE, NEW YORK**

Pumpage

| <i>Production/ Extraction Well</i> | <i>Pumping Rate (gpm)</i> | <i>Refined Model Layer Where Pumping was Simulated ⁽¹⁾</i> |
|--|-------------------------------|---|
| VCM Subplume Containment System | | |
| SPPW-1 | 500 | 4 & 5 |
| SPPW-2 | 250 | 6 & 7 |
| SPPW-3 | 250 | 6 & 7 |
| Nothrop IRM ⁽²⁾ | | |
| GP-1 | 1,075 | 10 & 11 |
| ONCT-1D | 1,000 | 10 & 11 |
| ONCT-2D | 600 | 10 & 11 |
| ONCT-3D | 700 | 10 & 11 |

Discharge

| <i>Discharge Basin</i> | <i>Number of Refined Model Cells and Location Where Discharge was Simulated ⁽³⁾</i> | <i>Discharge Rate (gpm)</i> |
|--|--|---------------------------------|
| VCM Subplume Containment System | | |
| Sump 1 | 2, Southeast corner of Hooker/Ruco Site | 50 |
| Sump 2 | 3, Southeast corner of Hooker/Ruco Site | 50 |
| New Sump | 9, Northwest corner of Hooker/Ruco Site | 900 |
| Nothrop IRM ⁽²⁾ | | |
| Plant 5 Basins | 39, South of Northrop Plant 5 | 1,215 |
| Southern Basins | 60, Southeast of Northrop Plant 2 | 2,231 |

Notes:

- (1) The extraction well pumpage was divided equally between the two refined model layers indicated.
- (2) The current Northrop IRM pumpage and recharge rates are presented in Table A.3.1.
- (3) The recharge was applied in the refined model layer 1.

APPENDIX B
ALTERNATIVE COST SUMMARY TABLES

TABLE B.1
 ALTERNATIVE 3A
 OU-3 REMEDY COST ESTIMATES
 HICKSVILLE, NEW YORK

CAPITAL COSTS

| | | |
|---|----|-----------|
| • Well Installation | | |
| - Large Pumping Well | \$ | 150,000 |
| - Two smaller pumping wells | \$ | 200,000 |
| - 2 monitoring well nests | \$ | 160,000 |
| • Well Pumps | | |
| - Large Well | \$ | 25,000 |
| - Two smaller well(s) | \$ | 10,000 |
| • Forcemain | | |
| - Wells to Treatment Building | \$ | 275,000 |
| - Treatment Building to Recharge Basin | \$ | 105,000 |
| • Recharge Basin | | |
| - Investigations and Evaluations | \$ | 5,000 |
| - Construction (soil disposed off-site as clean fill) | \$ | 300,000 |
| • Land Purchase/Access Payments | | |
| - Wells/Forcemain | \$ | 50,000 |
| • VCM Treatment System | | |
| i) Equipment | | |
| - Pumps | \$ | 12,000 |
| - Tanks | \$ | 75,000 |
| - Air Stripper | \$ | 120,000 |
| - Catalytic Oxidizer | \$ | 250,000 |
| - Filters | \$ | 20,000 |
| - Taxes | \$ | 24,000 |
| ii) Materials and Installation | | |
| - Site Improvements | \$ | 20,000 |
| - Concrete Structures | \$ | 120,000 |
| - Equipment Super Structure | \$ | 50,000 |
| - Building Super Structure | \$ | 60,000 |
| - Piping, Millwrighting | \$ | 180,000 |
| - Instrumentation | \$ | 90,000 |
| - Electrical | \$ | 110,000 |
| - Insulation | \$ | 37,000 |
| - Painting | \$ | 25,000 |
| - Rigging | \$ | 44,000 |
| Sub-total | \$ | 2,517,000 |

TABLE B.1
ALTERNATIVE 3A
OU-3 REMEDY COST ESTIMATES
HICKSVILLE, NEW YORK

CAPITAL COSTS

| | |
|-----------------------------|---------------------|
| Engineering and Procurement | \$ 252,000 |
| Field Construction Expense | \$ <u>126,000</u> |
| Subtotal | \$ 2,895,000 |
| Contingency (20%) | \$ <u>579,000</u> |
| TOTAL CAPITAL | \$ 3,474,000 |

ANNUAL OPERATION AND MAINTENANCE

| | <i>Low Conc.</i> | <i>High Conc.</i> |
|-------------------------------|-------------------|-------------------|
| • VCM Treatment System | \$ 260,000 | \$ 300,000 |
| • VCM Monitoring | | |
| - Sentinel Wells | \$ 28,000 | \$ 28,000 |
| (12 wells - semi-annually) | | |
| - Treatment System | \$ 19,000 | \$ 19,000 |
| (monthly) | | |
| • Reporting | \$ 34,000 | \$ 34,000 |
| (Monthly) | | |
| • Labor | \$ 65,000 | \$ 65,000 |
| (1 person full time) | | |
| • Equipment Replacement | \$ 130,000 | \$ 130,000 |
| (5% of Capital Sub-total) | | |
| Sub-total | \$ <u>536,000</u> | \$ <u>576,000</u> |
| Contingency (20%) | \$ <u>107,000</u> | \$ <u>115,000</u> |
| TOTAL ANNUAL O&M | \$ 643,000 | \$ 691,000 |
| PRESENT WORTH | | |
| (5 years, 5% discount factor) | \$ 6,258,000 | \$ 6,465,000 |

TABLE B.2

**ALTERNATIVE 3B
OU-3 REMEDY COST ESTIMATES
HICKSVILLE, NEW YORK**

CAPITAL COSTS

| | | |
|---|----|-----------|
| • Well Installation | | |
| - Large Pumping Well | \$ | 150,000 |
| - Two smaller pumping wells | \$ | 250,000 |
| - 2 monitoring well nests | \$ | 160,000 |
| • Well Pumps | | |
| - Large Well | \$ | 25,000 |
| - Two smaller well(s) | \$ | 25,000 |
| • Forcemain | | |
| - Wells to Treatment Building | \$ | 325,000 |
| - Treatment Building to Recharge Basin | \$ | 120,000 |
| • Recharge Basin | | |
| - Investigations and Evaluations | \$ | 5,000 |
| - Construction (soil disposed off-site as clean fill) | \$ | 50,000 |
| • Land Purchase/Access Payments | | |
| - Wells/Forcemain | \$ | 300,000 |
| • VCM Treatment System | | |
| i) Equipment | | |
| - Pumps | \$ | 20,000 |
| - Tanks | \$ | 100,000 |
| - Air Stripper | \$ | 160,000 |
| - Catalytic Oxidizer | \$ | 375,000 |
| - Filters | \$ | 30,000 |
| - Taxes | \$ | 40,000 |
| ii) Materials and Installation | | |
| - Site Improvements | \$ | 24,000 |
| - Concrete Structures | \$ | 140,000 |
| - Equipment Super Structure | \$ | 65,000 |
| - Building Super Structure | \$ | 70,000 |
| - Piping, Millwrighting | \$ | 225,000 |
| - Instrumentation | \$ | 110,000 |
| - Electrical | \$ | 140,000 |
| - Insulation | \$ | 46,000 |
| - Painting | \$ | 31,000 |
| - Rigging | \$ | 54,000 |
| Sub-total | \$ | 3,040,000 |

TABLE B.2

ALTERNATIVE 3B
OU-3 REMEDY COST ESTIMATES
HICKSVILLE, NEW YORK

CAPITAL COSTS

| | |
|-----------------------------|-------------------|
| Engineering and Procurement | \$ 304,000 |
| Field Construction Expense | \$ <u>152,000</u> |
| Subtotal | \$ 3,496,000 |
| Contingency (20%) | \$ <u>699,000</u> |
| TOTAL CAPITAL | \$ 4,195,000 |

ANNUAL OPERATION AND MAINTENANCE

| | <i>Low Conc.</i> | <i>High Conc.</i> |
|---|-------------------|-------------------|
| • VCM Treatment System | \$ 260,000 | \$ 300,000 |
| • VCM Monitoring | | |
| - Sentinel Wells | \$ 28,000 | \$ 28,000 |
| (10 wells - semi-annually) | | |
| - Treatment System | \$ 19,000 | \$ 19,000 |
| (monthly) | | |
| • Reporting (Monthly) | \$ 34,000 | \$ 34,000 |
| • Labor (1 person full time) | \$ 65,000 | \$ 65,000 |
| • Equipment Replacement (5% of Capital Sub-total) | \$ 160,000 | \$ 160,000 |
| Sub-total | \$ <u>566,000</u> | \$ <u>606,000</u> |
| Contingency (20%) | \$ <u>113,000</u> | \$ <u>121,000</u> |
| TOTAL ANNUAL O&M | \$ 679,000 | \$ 727,000 |
| PRESENT WORTH (30 years, 5% discount factor) | \$ 14,633,000 | \$ 15,370,000 |

TABLE B.3

**ALTERNATIVES 4A, 4B AND 4C
OU-3 REMEDY COST ESTIMATES
HICKSVILLE, NEW YORK**

| | <i>4A</i> | <i>4B</i> | <i>4C</i> |
|------------------------------|--------------------|--------------------|--------------------|
| <i>CAPITAL COSTS</i> | | | |
| 1 Well Installations | | | |
| A Injection | \$337,500 | \$337,500 | \$270,000 |
| B Monitoring | \$90,000 | \$90,000 | \$90,000 |
| 2 Forcemain | | | |
| A Header Piping | \$0 | \$0 | \$190,000 |
| B Down Well Piping | \$12,000 | \$12,000 | \$0 |
| 3 Land Purchase | \$150,000 | \$150,000 | \$150,000 |
| 4 Materials and Installation | | | |
| A Site Improvements | \$45,000 | \$45,000 | \$17,000 |
| B Equipment | \$275,000 | \$275,000 | \$135,000 |
| C Mechanical | \$225,000 | \$225,000 | \$25,000 |
| D Electrical | \$0 | \$0 | \$36,000 |
| Subtotal | \$1,134,500 | \$1,134,500 | \$913,000 |
| Engineering (10%) | \$113,450 | \$113,450 | \$91,300 |
| Field Construction (5%) | \$56,725 | \$56,725 | \$45,650 |
| Subtotal | \$1,304,675 | \$1,304,675 | \$1,049,950 |
| Contingency (20%) | \$260,935 | \$260,935 | \$209,990 |
| TOTAL CAPITAL | \$1,565,610 | \$1,565,610 | \$1,259,940 |

TABLE B.3

**ALTERNATIVES 4A, 4B AND 4C
OU-3 REMEDY COST ESTIMATES
HICKSVILLE, NEW YORK**

ANNUAL O & M

| | | | |
|--|------------------|------------------|------------------|
| 5 VCM Treatment System Additives | \$25,500 | \$58,500 | \$0 |
| 6 VCM Monitoring | \$28,000 | \$28,000 | \$28,000 |
| 7 Utilities | | | |
| A Electric | \$0 | \$0 | \$93,000 |
| B Water | \$5,000 | \$5,000 | \$0 |
| 8 Reporting | \$34,000 | \$34,000 | \$34,000 |
| 9 Labor (full time) | \$65,000 | \$65,000 | \$65,000 |
| 10 Equipment Replacement (5%) | \$56,725 | \$56,725 | \$45,650 |
| Subtotal | \$214,225 | \$247,225 | \$265,650 |
| Contingency (20%) | \$42,845 | \$49,445 | \$53,130 |
| TOTAL ANNUAL COSTS | \$257,070 | \$296,670 | \$318,780 |
| Source Treatment O & M Pres Worth | | | |
| 3 Year Treatment | | | \$868,117 |
| 5 Year Treatment | | \$1,284,426 | |
| 10 Year Treatment | \$1,985,026 | | |
| Final Enhanced Bioremediation O & M Pres Worth | | | |
| Years 3-5 | \$412,913 | | |
| Years 5-7 | \$374,524 | | |
| Enhanced Bioremediation - 10 years | | \$3,550,636 | |
| Chemical Oxidation 5 Years, ENA 2 Years | | \$3,224,560 | |
| Biosparging 3 Years, ENA 2 Years | | \$2,540,970 | |

APPENDIX C
MASS FLUX ESTIMATES
OU-1 GROUNDWATER CONTRIBUTIONS TO OU-3 GROUNDWATER

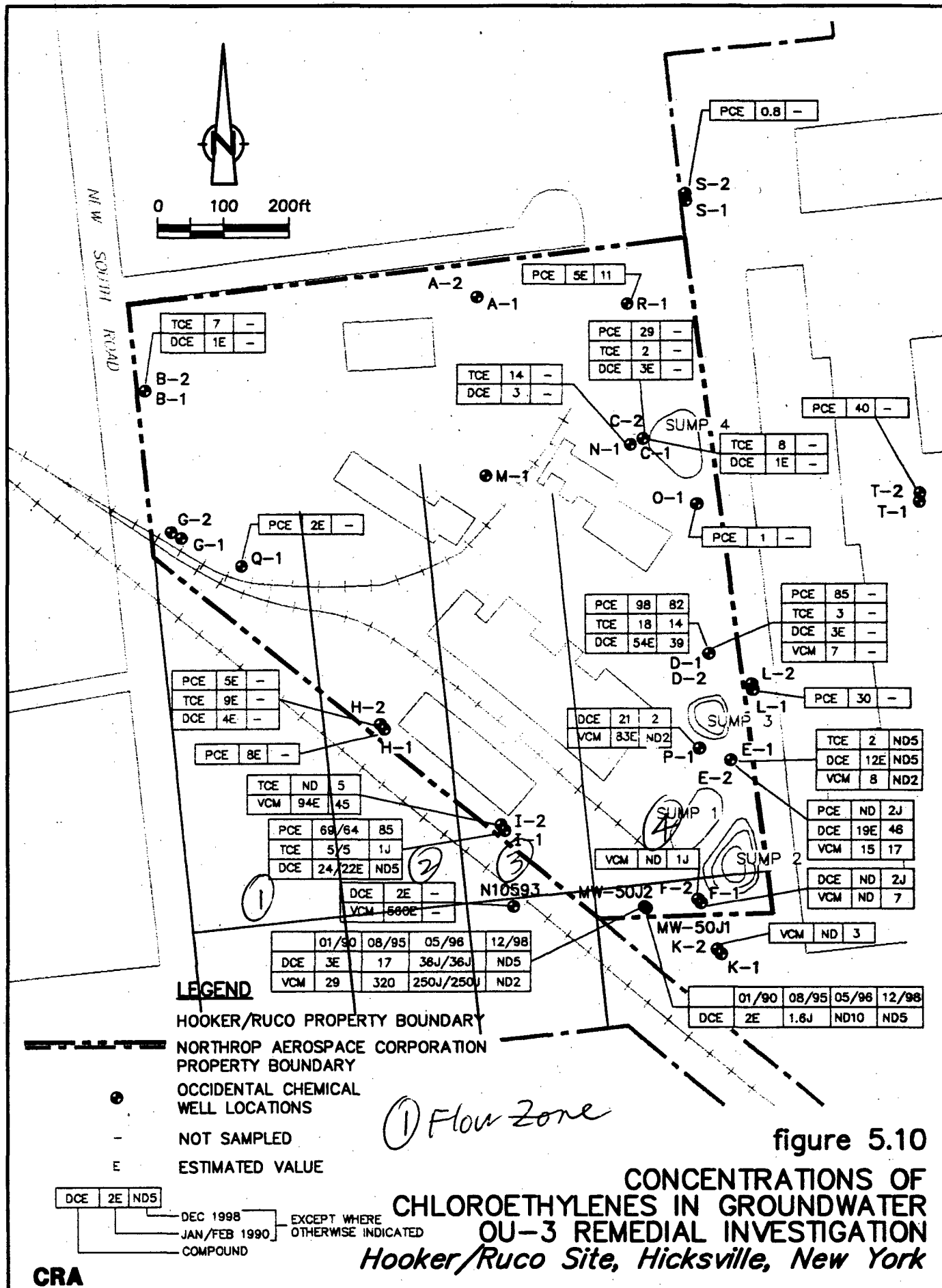


figure 5.10

TABLE C.1
ESTIMATE OF GROUNDWATER FLOW FROM THE HOOKER/RUCO SITE

| Model Layer | Depth (ft bgs) | Saturated Thickness (ft) (D) | Hydraulic Conductivity (K) (ft/day) (8) | Gradient (i) | Width of Cross-Section (L) (ft) (2) | | | | Groundwater Flow (Q=KiLD) (ft ³ /day) | | | |
|-------------|----------------|------------------------------|---|--------------|-------------------------------------|-----|-----|-----|--|-------------|-------------|-------------|
| | | | | | 1 | 2 | 3 | 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 |
| 1 | 0 to 90 | 40 (1) | 200 | 0.002 | 230 | 180 | 190 | 260 | 3,680 | 2,880 | 3,040 | 4,160 |
| 2 | 90 to 105 | 15 | 200 | 0.002 | 230 | 180 | 190 | 260 | 1,380 | 1,080 | 1,140 | 1,560 |
| 3 | 105 to 180 | 75 | 120 | 0.002 | 230 | 180 | 190 | 260 | 4,140 | 3,240 | 3,420 | 4,680 |
| 4 | 180 to 270 | 90 | 30 | 0.002 | 230 | 180 | 190 | 260 | 1,242 | 972 | 1,026 | 1,404 |
| 5 | 270 to 365 | 95 | 30 | 0.002 | 230 | 180 | 190 | 260 | 1,311 | 1,026 | 1,083 | 1,482 |
| 6 | 365 to 495 | 130 | 30 | 0.002 | 230 | 180 | 190 | 260 | 1,794 | 1,404 | 1,482 | 2,028 |
| 7 | 495 to 610 | 115 | 30 | 0.002 | 230 | 180 | 190 | 260 | 1,587 | 1,242 | 1,311 | 1,794 |
| 8 | 610 to 680 | 70 | 60 | 0.002 | 230 | 180 | 190 | 260 | 1,932 | 1,512 | 1,596 | 2,184 |

Total

Notes:

NS - Not sampled

(1) Assuming depth to groundwater = 50 ft bgs.

(2) Flow Zones shown on attached Figure 5.10.

(3) Assumed.

(4) From 1999 OU-3 RI, Appendix H.

TABLE C.2

ESTIMATE OF PCE GROUNDWATER CHEMICAL LOADING
LEAVING THE HOOKER/RUCO SITE

| Model Layer | Groundwater Flow (Q=KiLD) (ft ³ /day) | | | | PCE Groundwater Concentration ⁽¹⁾ (µg/L) | | | | PCE Chemical Flux ⁽²⁾ (lbs/day) | | | |
|----------------|---|-------------|-------------|-------------|--|------------------|-------------------|------------------|---|-------------|-------------|-------------|
| | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 |
| 1 | 3,680 | 2,880 | 3,040 | 4,160 | 2 | 8 | 85 | 0 | 0.0005 | 0.0014 | 0.0161 | 0 |
| 2 | 1,380 | 1,080 | 1,140 | 1,560 | 0 ⁽³⁾ | 0 ⁽³⁾ | 42 ⁽⁴⁾ | 0 | 0 | 0 | 0.0030 | 0 |
| 3 | 4,140 | 3,240 | 3,420 | 4,680 | 0 ⁽³⁾ | 5 ⁽³⁾ | 0 | 0 | 0 | 0.0010 | 0 | 0 |
| 4 | 1,242 | 972 | 1,026 | 1,404 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 110 | 0 | 0 | 0 | 0.0096 |
| 5 | 1,311 | 1,026 | 1,083 | 1,482 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 67 | 0 | 0 | 0 | 0.0062 |
| 6 | 1,794 | 1,404 | 1,482 | 2,028 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 7 | 1,587 | 1,242 | 1,311 | 1,794 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 8 | 1,932 | 1,512 | 1,596 | 2,184 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 |
| Total | | | | | | | | | 0.0005 | 0.0024 | 0.0191 | 0.0158 |

Total PLE Plus = 0.0379

Notes:

- (1) Based on most recent results shown on Figures 5.10 and 5.13 of Draft OU-3 RI Report (Revised November 1999), ND results assigned value of 0.
- (2) $MF = Q \left(\frac{ft^3}{day} \right) \times 62.4 \frac{lbs}{ft^3} \times C \times 10^{-9} = \text{lbs/day}$.
- (3) Assigned value of 0 based on ND or low level concentration in overlying layer.
- (4) Assumed to be average of the overlying and underlying Model Layer concentrations.

TABLE C.3

ESTIMATE OF TCE GROUNDWATER CHEMICAL LOADING
LEAVING THE HOOKER/RUCO SITE

| Model Layer | Groundwater Flow (Q=KiLD) (ft ³ /day) | | | | TCE Groundwater Concentration ⁽¹⁾ (µg/L) | | | | TCE Chemical Flux ⁽²⁾ (lbs/day) | | | |
|----------------|---|-------------|-------------|-------------|--|------------------|------------------|------------------|---|-------------|-------------|-------------|
| | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 |
| 1 | 3,680 | 2,880 | 3,040 | 4,160 | 0 | 0 | 1 | 0 | 0 | 0 | 0.0002 | 0 |
| 2 | 1,380 | 1,080 | 1,140 | 1,560 | 0 ⁽³⁾ | 5 ⁽⁴⁾ | 3 ⁽⁴⁾ | 0 | 0 | 0.0003 | 0.0002 | 0 |
| 3 | 4,140 | 3,240 | 3,420 | 4,680 | 0 ⁽³⁾ | 9 | 5 | 0 | 0 | 0.0018 | 0.0011 | 0 |
| 4 | 1,242 | 972 | 1,026 | 1,404 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 450 | 0 | 0 | 0 | 0.0394 |
| 5 | 1,311 | 1,026 | 1,083 | 1,482 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 110 | 0 | 0 | 0 | 0.0102 |
| 6 | 1,794 | 1,404 | 1,482 | 2,028 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 7 | 1,587 | 1,242 | 1,311 | 1,794 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 8 | 1,932 | 1,512 | 1,596 | 2,184 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 |
| Total | | | | | | | | | 0 | 0.0022 | 0.0015 | 0.0496 |

Total PLE Plus = 0.0532

Notes:

- (1) Based on most recent results shown on Figures 5.10 and 5.11 of Draft OU-3 RI Report (Revised November 1999), ND results assigned value of 0.
- (2) $MF = Q \left(\frac{\text{ft}^3}{\text{day}} \right) \times 62.4 \frac{\text{lbs}}{\text{ft}^3} \times C \times 10^{-9} = \text{lbs/day}$.
- (3) Assigned value of 0 based on ND or low level concentration in overlying layer.
- (4) Assumed to be one half the overlying and underlying model layer concentrations.

TABLE C.4

ESTIMATE OF VCM GROUNDWATER CHEMICAL LOADING
LEAVING THE HOOKER/RUCO SITE

| Model Layer | Groundwater Flow (Q=KiLD) (ft ³ /day) | | | | VCM Groundwater Concentration ⁽¹⁾ (µg/L) | | | | VCM Chemical Flux ⁽²⁾ (lbs/day) | | | |
|----------------|---|-------------|-------------|-------------|--|------------------|--------------------|------------------|---|-------------|-------------|-------------|
| | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 |
| | | | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1 | 3,680 | 2,880 | 3,040 | 4,160 | 0 | 0 | 560 | 0 | 0 | 0 | 0.1062 | 0 |
| 2 | 1,380 | 1,080 | 1,140 | 1,560 | 0 ⁽³⁾ | 0 | 303 ⁽⁴⁾ | 0 | 0 | 0 | 0.0216 | 0 |
| 3 | 4,140 | 3,240 | 3,420 | 4,680 | 0 ⁽³⁾ | 0 ⁽³⁾ | 45 | 0 | 0 | 0 | 0.0096 | 0 |
| 4 | 1,242 | 972 | 1,026 | 1,404 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 210 | 0 | 0 | 0 | 0.0184 |
| 5 | 1,311 | 1,026 | 1,083 | 1,482 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 6 | 1,794 | 1,404 | 1,482 | 2,028 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 7 | 1,587 | 1,242 | 1,311 | 1,794 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 | 0 |
| 8 | 1,932 | 1,512 | 1,596 | 2,184 | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 ⁽³⁾ | 0 | 0 | 0 | 0 |
| Total | | | | | | | | | 0 | 0 | 0.1374 | 0.0184 |

Total PLE Plus = 0.1558

Notes:

(1) Based on most recent results shown on Figures 5.10 and 5.15 of Draft OU-3 RI Report (Revised November 1999), ND results assigned value of 0.

$$(2) \text{ MF} = Q \left(\frac{\text{ft}^3}{\text{day}} \right) \times 62.4 \frac{\text{lbs}}{\text{ft}^3} \times C \times 10^{-9} = \text{ lbs/day.}$$

(3) Assigned value of 0 based on ND or low level concentration in overlying layer.

(4) Assumed to be average of the overlying and underlying Model Layer concentrations.

TABLE C.5

ESTIMATE OF SVOC TICs GROUNDWATER CHEMICAL LOADING
LEAVING THE HOOKER/RUCO SITE

| Model Layer | Groundwater Flow (Q=KiLD) (ft ³ /day) | | | | SVOC TIC Groundwater Concentration ⁽¹⁾ (µg/L) | | | | SVOC TIC Chemical Flux ⁽²⁾ (lbs/day) | | | |
|----------------|---|-------------|-------------|-------------|---|------------------|-------------------|--------------------|--|-------------|-------------|-------------|
| | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 | Flow Zone 1 | Flow Zone 2 | Flow Zone 3 | Flow Zone 4 |
| 1 | 3,680 | 2,880 | 3,040 | 4,160 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 29 | 391 | 0 | 0 | 0.0055 | 0.1015 |
| 2 | 1,380 | 1,080 | 1,140 | 1,560 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 18 ⁽⁴⁾ | 403 ⁽⁴⁾ | 0 | 0 | 0.0013 | 0.0392 |
| 3 | 4,140 | 3,240 | 3,420 | 4,680 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 7 | 414 | 0 | 0 | 0.0015 | 0.1209 |
| 4 | 1,242 | 972 | 1,026 | 1,404 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 0 ⁽³⁾ | 215 ⁽⁴⁾ | 0 | 0 | 0 | 0.0188 |
| 5 | 1,311 | 1,026 | 1,083 | 1,482 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 0 ⁽³⁾ | 16 | 0 | 0 | 0 | 0.0015 |
| 6 | 1,794 | 1,404 | 1,482 | 2,028 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 0 ⁽³⁾ | 85 | 0 | 0 | 0 | 0.0108 |
| 7 | 1,587 | 1,242 | 1,311 | 1,794 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 0 ⁽³⁾ | 0 ⁽⁶⁾ | 0 | 0 | 0 | 0 |
| 8 | 1,932 | 1,512 | 1,596 | 2,184 | 0 ⁽⁵⁾ | 0 ⁽⁵⁾ | 0 ⁽³⁾ | 0 ⁽⁶⁾ | 0 | 0 | 0 | 0 |
| Total | | | | | | | | | 0 | 0 | 0.0083 | 0.2927 |

Total PLE Plus = 0.3010

Notes:

- (1) Based on most recent results shown on Figure 5.19 of Draft OU-3 RI Report (Revised November 1999), ND results assigned value of 0.
- (2) $MF = Q \left(\frac{ft^3}{day} \right) \times 62.4 \frac{lbs}{ft^3} \times C \times 10^{-9} = \text{lbs/day}$
- (3) Assigned value of 0 based on ND or low level concentration in overlying layer.
- (4) Assumed to be average of the overlying and underlying Model Layer concentrations.
- (5) Assumed to be 0 because Flow Zones 1 and 2 are cross-gradient to areas where TICs were discharged on-Site.

D

400254

APPENDIX D

RESULTS OF LITERATURE SEARCH ON CHEMICAL OXIDATION



Laboratory and controlled field experiments using potassium permanganate to remediate trichloroethylene and perchloroethylene DNAPLs in porous media

M. Schnarr ^a, C. Truax ^b, G. Farquhar ^{c,*}, E. Hood ^c, T. Gonullu ^c,
B. Stickney ^c

^a *Geotrans, Boulder, Co, USA*

^b *Jacques Whitford, Vancouver, BC, Canada*

^c *Department of Civil Engineering, University of Waterloo, Waterloo, Ont., N2L 3G1, Canada*

Received 30 December 1994; revised 18 December 1996; accepted 18 December 1996

Abstract

Few proven technologies exist that may be used to treat dense non-aqueous phase liquid (DNAPL) contaminants. In-situ chemical flushing is a proposed technology which consists of flushing DNAPL source zones with a reactive solution to degrade the contaminant mass below ground.

A laboratory and controlled field experimental program was conducted to assess the potential of potassium permanganate (KMnO_4) as a reagent for in-situ DNAPL remediation. The results of laboratory experiments indicated that two common DNAPL contaminants, perchloroethylene (PCE) and trichloroethylene (TCE), were rapidly degraded to chloride and carbon dioxide. Column experiments, using residual PCE flushed with oxidant concentrations as high as 10 g L^{-1} , indicated that chloride could be used as a reaction tracer. From the chloride data, it appeared that the rate of PCE removal from the columns was a complex process dependent upon the kinetics of both dissolution and oxidation.

Two experimental applications of in-situ oxidation were conducted in the Borden aquifer isolated within a 7.5 m^3 double sheet-pile cell. The cell was fitted with injection and recovery wells through which aqueous solutions of KMnO_4 were flushed to oxidize solvent source zones in situ. In the initial experiment, flushing of a 1 L PCE residual source with 10 g L^{-1} KMnO_4 at total flow rates of up to 100 L per day, completely removed the source within 120 days. A second experiment, using an 8 L mixture of PCE and TCE slowly allowed to infiltrate into the cell, was

* Corresponding author.

conducted using a system to recycle the oxidant. The oxidant was added at 10 g L^{-1} with a flow of approximately 50 L per day. After 290 days of flushing, it was concluded from the monitoring data that 62% of the initial source (as equivalent chloride mass) had been oxidized and it was evident that oxidation was continuing in the upper third of the cell.

These experiments have suggested that the effectiveness of in-situ chemical oxidation will depend primarily upon the distribution of the DNAPL in the subsurface and its effects upon dissolution. In both experiments, spatial variability of chloride measurements appeared to reflect both the DNAPL location and distribution. © 1998 Elsevier Science B.V.

Keywords: Potassium permanganate; Porous media; DNAPL contaminants

1. Introduction

Trichloroethylene (TCE) and perchloroethylene (PCE) are two chlorinated organic solvents frequently identified as ground water aquifer contaminants (Westrick et al., 1984; Smith, 1990; Plumb, 1991). The US Environmental Protection Agency drinking water standards for each of these compounds is $5 \mu\text{g L}^{-1}$ compared with their solubilities of approximately $1,500 \text{ mg L}^{-1}$ and 240 mg L^{-1} , respectively (Pankow and Cherry, 1996). With five to six orders of magnitude difference between solubility and regulated concentration, the presence of dense non-aqueous phase liquids (DNAPLs), especially in the form of pools in the subsurface, will remain as a very long-term source of contamination until either source containment, isolation or removal has occurred (Mackay and Cherry, 1989; Johnson and Pankow, 1992).

Frequently at sites where DNAPLs are present, pump and treat remediation is selected as a remedial alternative; however, pump and treat approaches to aquifer restoration have demonstrated a distinct lack of success even at sites without DNAPLs (National Research Council, 1994). At sites where DNAPL is present, this approach is primarily limited by low contaminant solubility, contaminant mass storage in low permeability zones, and the relatively large masses of the DNAPL present in the aquifer (Doty and Travis, 1991). The lack of success of pump and treat at these sites has added emphasis to remedial efforts designed to isolate, remove or treat DNAPL sources with the potential benefits of reducing the duration of a subsequent pump and treat containment process and reducing downgradient aqueous phase concentrations.

One example of a mass treatment technology is in-situ oxidation, an approach which consists of flushing a zone of DNAPL contamination with a reactive solution. This technology is conceptually appealing since it combines hydraulic containment of a source zone with contaminant treatment below ground. Various reactive compounds have been suggested including hydrogen peroxide, Fenton's reagent, ozone and potassium permanganate (Cho and Bowers, 1991). To date, documented use of this technology is limited to a single industrial application in which hydrogen peroxide was used to remove an LNAPL release containing 50% formaldehyde with some success (Cowie and Weider, 1986). To our knowledge, the results presented in this paper are the first evaluation of potassium permanganate (KMnO_4) as an in-situ reagent and the first evaluation of in-situ chemical flushing of DNAPL contaminants.

2. Permanganate ion as an oxidant

The use of the permanganate ion (MnO_4^-) to indiscriminately scavenge and oxidize organic contaminants has a long history in both drinking water and wastewater treatment (Steel and McGhee, 1979; Eilbeck and Mattock, 1987), including removal of iron and manganese (Benefield et al., 1982), phenols (Vella et al., 1990), trihalomethane precursors (Colthurst and Singer, 1982) and more recently, TCE (Vella and Veronda, 1992). The reactive properties of MnO_4^- with both organic and inorganic compounds have been described in detail by Stewart (1965) and Lee (1980). Permanganate oxidation of organic compounds is used in the commercial production of various compounds with its most serious limitation being its lack of solubility in most hydrocarbons (Lee, 1980) including PCE and TCE. For example, MnO_4^- oxidation of alkenes is used in the synthesis of the corresponding glycols. In addition to its characteristics as an oxidant, potassium permanganate has a high aqueous solubility (64 g L^{-1} at 20°C (Perry et al., 1984)), a property which would allow for a significant loading rate of oxidant into a contaminated zone. As a solid, KMnO_4 is easily handled and currently costs approximately CDN\$4 per kg.

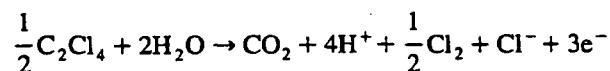
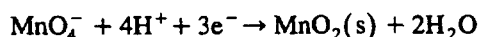
3. Oxidation mechanism

There are few references dealing directly with the oxidation of specific chlorinated organic compounds by KMnO_4 . In general, the existing research has focused on synthesis, rather than destruction, of commercially useful oxidation products from alkenes. Lee (1980) has identified two potential reaction mechanisms for alkene oxidation. Both mechanisms begin with the formation of a hypomanganate diester with subsequent steps generally dependent upon pH and the MnO_4^- concentration. Oxidation of alkenes is generally performed in an aqueous solution due to the fact that KMnO_4 is insoluble in most hydrocarbons without the use of a phase transfer catalyst (Lee, 1980).

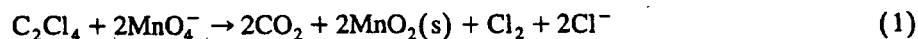
4. Oxidation stoichiometry

Based on laboratory observations and the redox reactions for each compound, overall reactions between KMnO_4 and TCE and PCE were determined. Laboratory observations leading to these equations include the formation of a brown precipitate, determined to be $\text{MnO}_2(\text{s})$, and the evolution of a gas, later confirmed as being CO_2 .

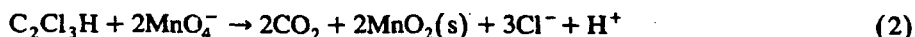
Recognizing that MnO_4^- was reduced to $\text{MnO}_2(\text{s})$ and assuming that the carbon in TCE and PCE was completely oxidized to CO_2 , the following half cell reactions apply:



which produce



In a similar fashion, the reaction for TCE is:



Stoichiometrically, 0.81 kg of Cl^- are produced per kg of TCE oxidized (Eq. (2)). A similar situation exists for PCE except that Eq. (1) suggests the formation of Cl_2 . Based on thermodynamic considerations, it was assumed that the Cl_2 is an intermediate and that Cl^- would be the sole chlorine species present. Therefore, oxidation of 1 kg of PCE should produce 0.86 g Cl^- .

5. Column experimentation: quantifying oxidation with chloride ion

5.1. Experimental outline

Eq. (1) and (2) suggest several possibilities for monitoring the progression of in situ oxidation applications. Some preliminary column experiments indicated that CO_2 in the gas and aqueous phases could be used as a reaction tracer during TCE oxidation but that this would be impractical in natural porous media containing carbonate minerals and natural organic matter. During these experiments significant gas production was observed; in one experiment, the extremely vigorous gas production actually disrupted the soil within the column. It was anticipated that measuring the variation in Cl^- in the effluent during oxidation would provide both a measure of the mass of TCE or PCE oxidized as well an indication of the relative rates of mass removal.

Chloride analyses were performed using an ORION ion selective electrode with a portable meter (ORION Model 720A). Measurements of KMnO_4 concentrations were performed either by titration with thiosulphate or spectrophotometrically (Spectronic 20D). Analysis of TCE and PCE was performed with a Shimadzu GC-9A gas chromato-

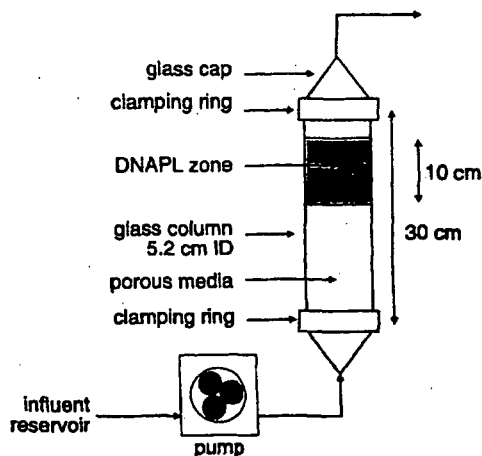


Fig. 1. Column apparatus; source consists of homogeneous PCE residual (1640 mg).

Table 1
Darcy flux and oxidant concentration for experimental columns

| | COL 1 | COL 2 | COL 3 | COL 4 | COL 5 |
|--|-------|-------|-------|-------|-------|
| Darcy flux (cm per day) | 42 | 42 | 63 | 68 | 61 |
| KMnO ₄ (g L ⁻¹) | 10 | 7.5 | 10 | 7.5 | 0 |
| Oxidant loading (g cm ⁻² per day) | 0.42 | 0.32 | 0.63 | 0.51 | 0 |
| Total mass removed @ 650 h (%) | 121 | 103 | 122 | 119 | 92 |
| % Mass removed as chloride | 92 | 91 | 96 | 93 | 0 |

Note: The cross-sectional area of each column was 20.3 cm²; porosity 0.41.

graph with a flame ionization detector and purge and trap unit operated according to EPA Method 601. During these experiments, the detection limits for PCE and TCE analyses were 10 µg L⁻¹.

To investigate the effects of oxidant concentration and flushing rates upon mass removal, five column experiments were performed using glass columns packed with fine grained sand samples (foc = 0.02%) from the Canadian Forces Base (CFB) Borden aquifer. In each of the column experiments, the sand was initially saturated with water and 1.0 mL of PCE added as a residual source (volumetric saturation ~ 1%) in the sand. Fig. 1 is a schematic diagram of the experimental apparatus. The columns were subsequently flushed with KMnO₄ solutions at the concentrations and average Darcy fluxes specified in Table 1. Actual flow rates into the columns were variable and were assumed to have produced the principal source of error. One column (COL 5) was flushed only with deionized water to evaluate mass removal by dissolution alone. After the oxidant flush, the columns were flushed with deionized water at the same flow rates.

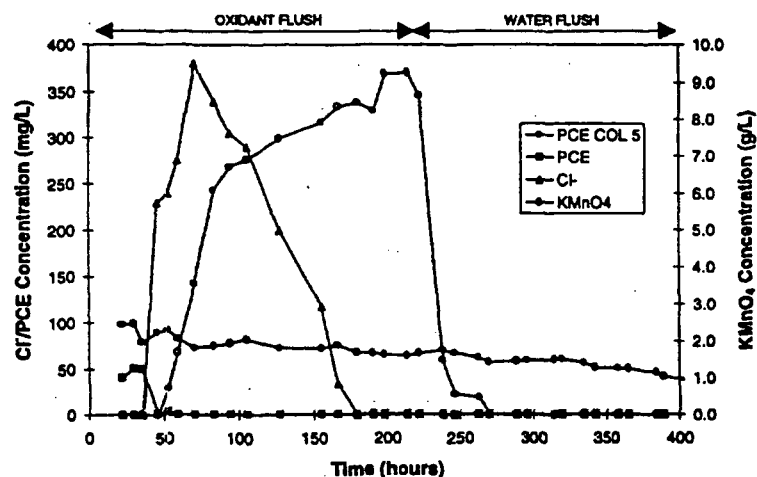


Fig. 2. Column effluent profiles for Cl⁻, PCE, input KMnO₄ and effluent KMnO₄. Also shown are effluent PCE concentrations for COL 5, which was flushed only with deionized water to compare mass removal by dissolution alone.

Control experiments confirmed that oxidation of the PCE was the only source of Cl^- from the columns.

Fig. 2 provides combined Cl^- , KMnO_4 and PCE effluent data for the experiment (COL 3) flushed at the highest oxidant loading and is qualitatively similar to results observed in the other columns. This column was flushed with an aqueous solution of 10

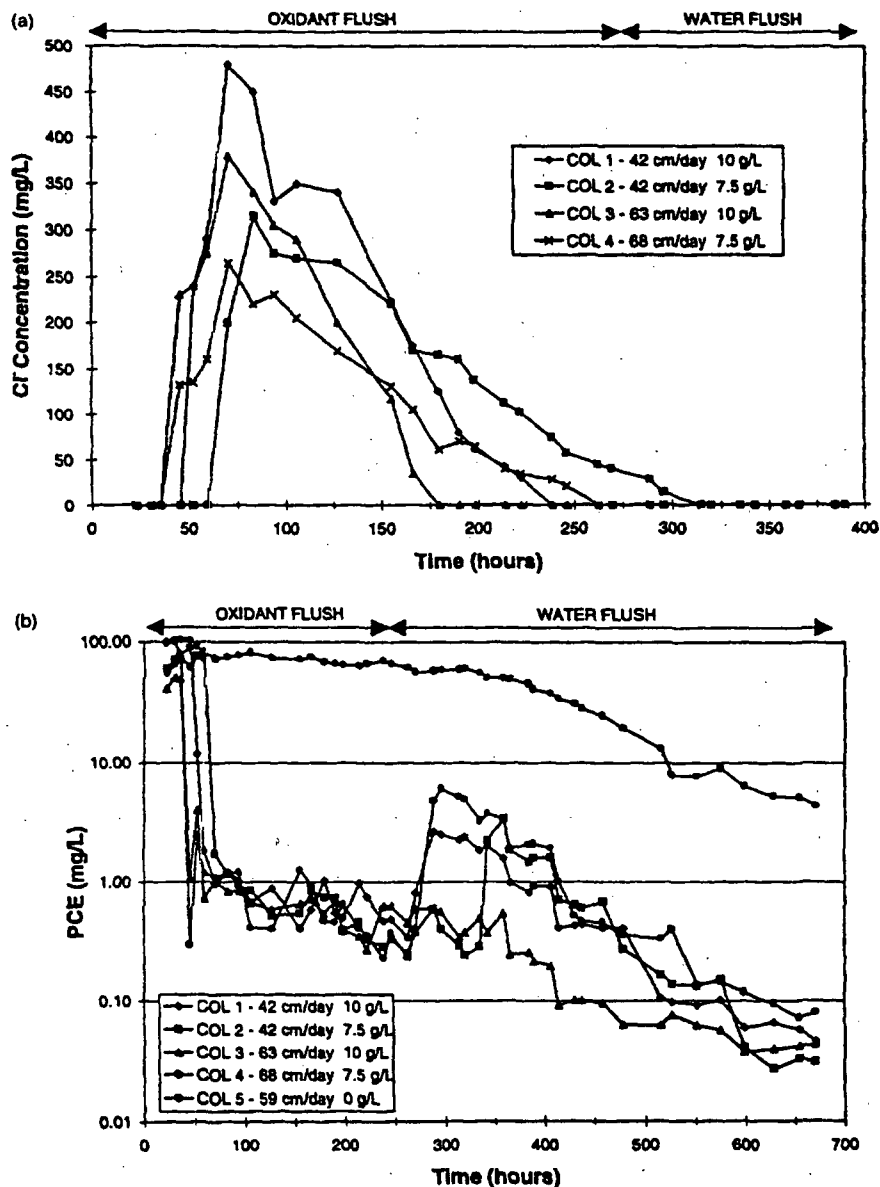


Fig. 3. (a) Effluent chloride concentrations (COL 1-4) and (b) effluent PCE concentrations (COL 1-5).

g L⁻¹ KMnO₄ for a period of 214 h and then deionized water for the remainder of the experiment.

In COL 3, PCE in the effluent was initially high (~50 mg L⁻¹). As the oxidant reached the source zone, Cl⁻ increased rapidly from non-detectable levels to a peak of 380 mg L⁻¹. When oxidant appeared in the effluent, the PCE concentrations dropped below 1 mg L⁻¹. The concentration of chloride began to decrease after 70 h of flushing and was less than 1 mg L⁻¹ after 180 h of flushing. This decline in Cl⁻ was accompanied by a gradual increase of KMnO₄ in the effluent to above 9 g L⁻¹ after 200 h (influent concentration of 10 g L⁻¹). The rate of PCE removal had reduced significantly after approximately 170 h.

In COL 5, the PCE concentration in the effluent from the column reached an initial peak of approximately 100 mg L⁻¹, and then declined slowly to a concentration of approximately 6 mg L⁻¹ after 650 h. The dissolution profile from COL 5 is representative of rate limited dissolution for this particular experimental setting.

Effluent Cl⁻ and PCE effluent concentrations for each of the columns are shown in Fig. 3(a) and (b). All of the columns flushed with oxidant initially produced no effluent Cl⁻. Chloride concentrations then rapidly rose to a peak and then slowly declined to non-detectable levels. The two columns flushed at 10 g L⁻¹ KMnO₄ producing larger chloride peaks. The initial delay in the appearance of Cl⁻ and KMnO₄ in the column effluents was attributed to displacement of the initial pore volume of deionized water and consumption of the KMnO₄ through oxidation of organic matter in the sand. In contrast, PCE concentrations in the columns flushed with oxidant were initially high (~100 mg L⁻¹) and then dropped below 1 mg L⁻¹. In each of these columns, the PCE concentrations tended to increase once the deionized water flush began suggesting that

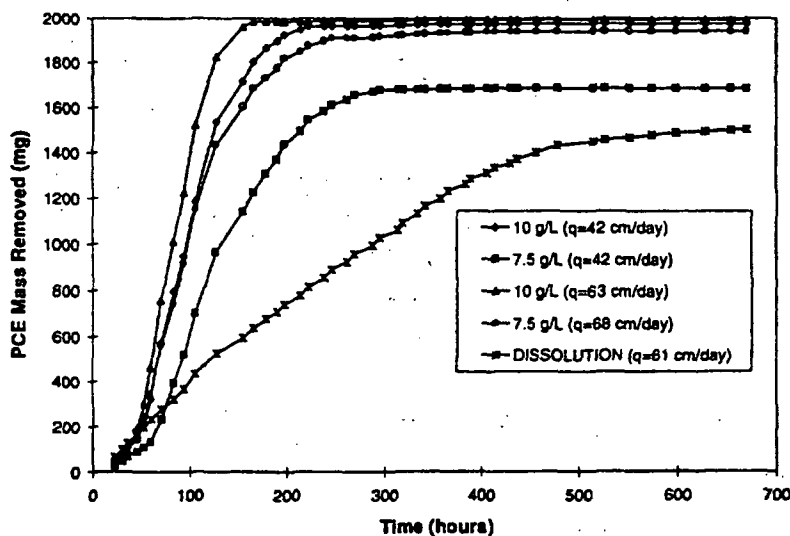


Fig. 4. Accumulated effluent Cl⁻ mass as a fraction of initial Cl⁻ mass in column. The accumulated mass remove includes both aqueous PCE and equivalent PCE mass oxidized as calculated from Cl⁻ data. The initial PCE mass was 1640 mg.

some PCE remained; however relative to the column flushed only with deionized water, effluent PCE concentrations were 1 to 2 orders of magnitude lower.

The accumulated equivalent PCE mass produced from each column is presented in Fig. 4; the mass of the initial PCE source was 1640 mg. The equivalent mass includes both effluent PCE and PCE oxidized calculated from Cl^- in the effluent. The mass balance over-estimates the initial mass of PCE from 103%–122%. This error in the mass balance was attributed mainly to variability in the flow rates.

During the deionized water flush following KMnO_4 addition, the PCE concentration in the effluents from COL 1, 2 and 4 increased from about 0.3 mg L^{-1} to as high as 6 mg L^{-1} then decreased below the detection limit. COL 3, which had the highest oxidant loading, did not experience this rebound. While most of the PCE had been oxidized in situ, a small amount of PCE remained within each column; however, for COL 3 and COL 4 (both flushed at close to the same flow rate as the dissolution control) the final effluent PCE concentrations were about 1% of those in COL 5.

6. Field experimentation

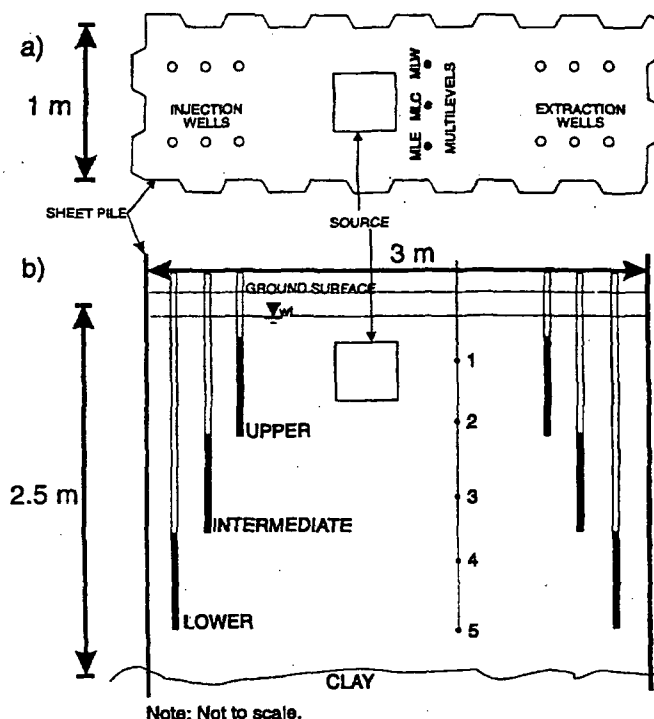
6.1. Experimental cell details

Two pilot scale experiments were performed at the CFB Borden research site in an unconfined, shallow aquifer consisting of a glaciolacustrine sand (Bolha, 1986). The sand is predominantly medium to fine grained and, while relatively homogeneous, contains numerous horizontal bedding features varying in thickness from millimeters to a few centimeters (Ball et al., 1990; Poulsen and Kueper, 1992). The mean hydraulic conductivity of the sand is $7.2 \times 10^{-3} \text{ cm s}^{-1}$ (Sudicky, 1986). The experimental cell, consisting of double-walled, sealed joint sheet piling (Starr et al., 1992) extended from the surface down to a clay aquitard at a depth of approximately 2.5 m (Fig. 5). The pore volume of the cell, estimated from the sand porosity of 0.33 (Ball et al., 1990), was approximately 2.48 m^3 .

Six injection and six extraction wells (2 in ID PVC) were located at opposite ends of the cell as shown; these were screened at upper, intermediate, and lower depths with each pair of well screens extending over one third of the depth. Also shown in Fig. 5 are the multilevel samplers which allowed collection of small volume samples from various points with the cell. The multilevel piezometers consisted of 0.06 in ID Teflon® tubes attached at 1 foot intervals to a central 0.5 in OD PVC pipe. The instrumentation was installed by simultaneously driving and jetting a 3 in ID steel casing to the required depth with a hand-held vibrating hammer, inserting the well casing or multilevel stem, withdrawing the larger steel casing and allowing the formation to collapse around the instrument.

6.2. Sampling methods

Sample collection from the multilevels was performed by connecting individual sample points to a 250 mL Erlenmeyer flask through a stopper. A vacuum was applied to the flask using a 50 mL syringe. Typically, 75–100 mL of sample were collected. Part of this volume was decanted into an 8 mL vial with Teflon® lined septa for TCE



Note: Not to scale.

Fig. 5. Schematic diagram of experiment cell at CFB Borden field site, including (a) plan view and (b) cross-section, illustrating location of instrumentation and NAPL sources.

and PCE analysis. A small quantity of granular sodium thiosulphate was added to reduce any KMnO_4 and prevent further solvent oxidation. The remaining volume was stored in a 40 mL EPA vial for Cl^- analysis. Sample analyses were conducted using the previously mentioned analytical methods.

7. Experiment I: homogeneous residual source

The DNAPL source for Experiment I consisted of 1 L (1.64 kg) of PCE which was mixed with soil taken from a $0.3 \text{ m} \times 0.3 \text{ m} \times 0.35 \text{ m}$ block below the water table. The soil:DNAPL mixture was replaced in the excavated block (Fig. 5). The residual DNAPL saturation was estimated to be 8% (v/v). The cell was subsequently flushed with a 10 g L^{-1} aqueous solution of KMnO_4 through the injection wells; effluent was withdrawn from the extraction wells. Constant head was maintained in the injection wells by siphoning from a constant head reservoir into each well. Flow rates were controlled by a peristaltic pump at the extraction wells. Initially, both the upper and intermediate extraction wells were pumped at a total flow rate of approximately 100 L per day. After monitoring confirmed that oxidation was occurring only in the upper third of the cell, pumping from the intermediate extraction wells was stopped at 1200 h with the new flow rate of 50 L per day from the upper wells. The cell was flushed with oxidant

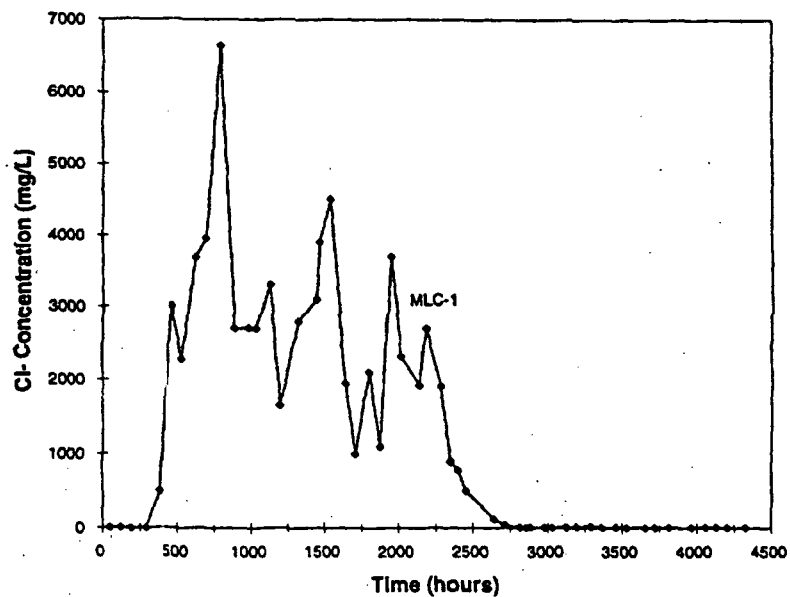


Fig. 6. Chloride concentrations observed at MLC-1, directly downgradient of the residual PCE source.

solution for 120 days and then with water for a further 60 days to displace the remaining oxidant and reaction products. Effluent from the cell was continuously treated to remove residual oxidant and aqueous phase PCE.

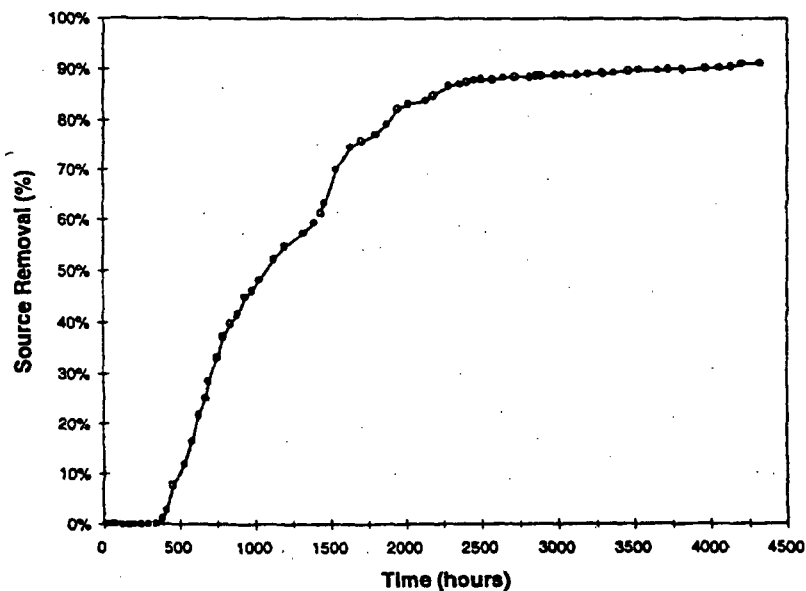


Fig. 7. Accumulated PCE mass destruction calculated based on observed chloride concentrations.

Chloride monitoring from the multilevel piezometers indicated that Cl^- was produced only in the upper third of the cell. After approximately 300 h of flushing, a rapid increase in Cl^- was observed in MLC-1 (Fig. 6). Over the remainder of the experiment, Cl^- concentrations at this point gradually declined to non-detectable levels. Using the Cl^- data from the extraction wells, the cumulative mass of effluent Cl^- was determined to be 1486 g or 91% of the chloride content of the initial source mass (Fig. 7).

Several other quantitative measures were used to evaluate the effectiveness of this experiment. PCE was not detected during the post-oxidation water flush. As well, a core was removed from the source zone after the water flush from which subsamples were taken and analyzed for their PCE content. Solvent concentrations in these subsamples were below the method detection limit ($< 0.0003\%$ w/w).

8. Experiment II: heterogenous NAPL source

Experiment II had a mixture of PCE and TCE as a source; source emplacement was designed to simulate a slow leak release. Six 2.5 cm ID stainless steel pipes, 1.0 m long and equipped with drive points, were driven to a depth of 0.25 m in the centre of the cell in the same location as the Experiment I source. Equal masses of TCE and PCE (6.19 kg each, 8.0 L in total) were mixed with Sudan IV and distributed equally into the six source points over a period of 9 days. Volatilization of the TCE/PCE mixture was minimized by adding it below the water table; however, some minor loss from the separatory funnels containing the mixture was likely. The DNAPL mixture was allowed to migrate within the cell for an additional 10 days before beginning in-situ KMnO_4 oxidation.

No effort was made to determine the distribution of the DNAPL within the cell; however, DNAPL was withdrawn from several of the multilevel sampling points throughout the course of the experiment. Initially, pure phase was evident in all the MLW and MLC sampling points but as treatment proceeded, free product persisted at only the lowest point of the centre multilevel (MLC-5).

8.1. Treatment system

The treatment system was designed to supply KMnO_4 at a concentration of 10 g L^{-1} through all six injection wells at a total flow rate of 48 L per day using the system of peristaltic pumps and a constant head reservoir as in Experiment I.

In Experiment I, the effluent eventually contained unused oxidant at concentrations close to 10 g L^{-1} . An oxidant recycle system was used in Experiment II to reduce the amount of oxidant used and to eliminate the need for continuous effluent treatment. In this system (Fig. 8), effluent was pumped through a coarse cartridge filter and discharged to a equalization and settling tank for removal of suspended $\text{MnO}_2(\text{s})$ and other solids. The main effluent line was drained by gravity to the constant head injection reservoir. A sample loop from the main effluent line ran through a spectrophotometer and was used to monitor KMnO_4 concentrations. The spectrophotometer provided an input to a PID controller. In turn, the controller ran a peristaltic pump which diverted a fraction of the main effluent flow to a column packed with crystalline KMnO_4 . The

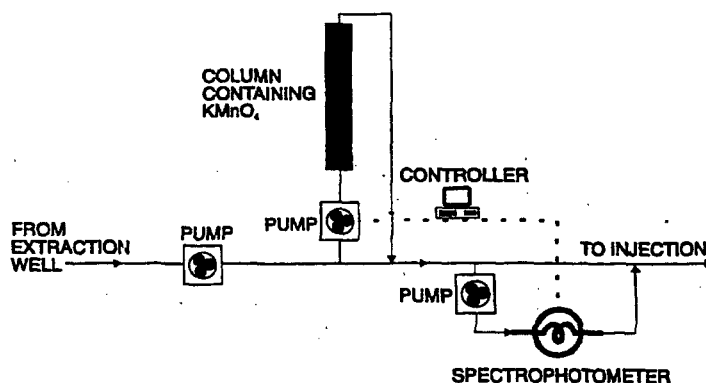


Fig. 8. Treatment schematic for Experiment II oxidant recycle system.

discharge from the column produced an oxidant solution near solubility (64 g L^{-1} at 20°C (Perry et al., 1984)). This stream was mixed back into the main effluent line before the spectrophotometer sample loop.

8.2. Cl^- concentration profiles in multilevels

Fig. 9 presents data from MLC. Low background Cl^- concentrations (generally less than 20 mg L^{-1}) were observed prior to KMnO_4 addition. After KMnO_4 addition, substantial increases in Cl^- concentration were observed. At three levels (MLC-2,

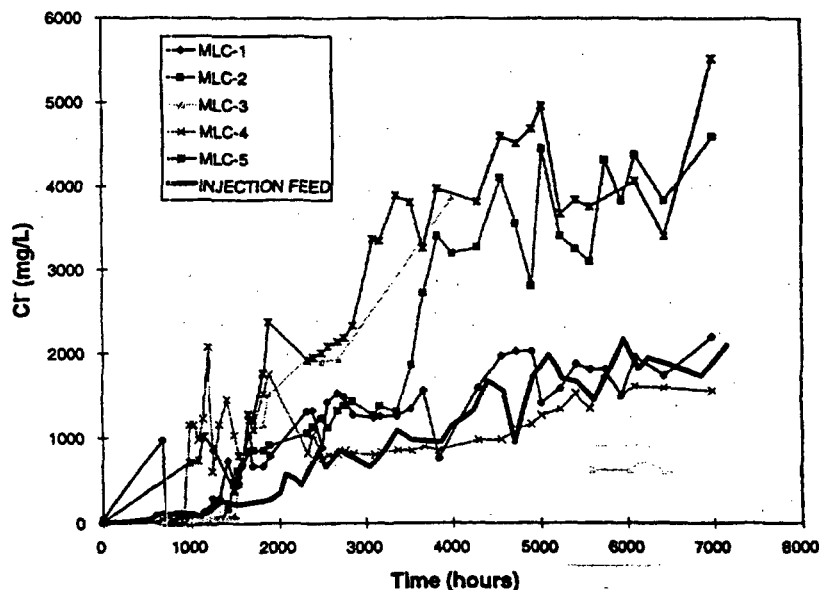


Fig. 9. Chloride concentrations observed in MLC (MLC 1 is the shallowest; MLC 5 is the deepest). The heavy line represents the variation of Cl^- in the injected oxidant solution.

MLC-3 and MLC-5), concentrations exceeded 3000 mg L^{-1} , indicating that significant oxidation was occurring adjacent to these points.

MLC-1 and MLC-4 exhibited little evidence of oxidation. Each experienced a gradual increase in Cl^- but this was owing principally to Cl^- in the recycled KMnO_4 solution. Cl^- concentrations at each of these two points were generally similar to the profile of injection feed concentrations indicating relatively little DNAPL oxidization at these depths.

8.3. Cl^- and solvent concentration profiles in extraction wells

PCE concentration data from the extraction wells are presented in Fig. 10; the data points are averages for the pair of wells at each depth. TCE concentrations (not shown) were generally similar but slightly higher. Some trends are evident in spite of high variability in the data. The highest concentrations of both solvents were observed in the upper wells. From 2000 to 2500 h, the concentrations of PCE were in the 10 to 50 mg L^{-1} range. During this time, the effluent from the extraction wells was nearly colourless indicating that most of the KMnO_4 had been consumed. Beyond this time, KMnO_4 concentrations began to increase in the effluent with a corresponding reduction in the PCE concentrations.

The PCE and TCE concentrations declined with time and after approximately 6000 h, remained at concentrations less than 0.01 mg L^{-1} . At this point, the effluent had high KMnO_4 concentrations approaching the injected concentration.

Chloride concentrations (Fig. 11) in all of the extraction wells increased over time owing to the recycling of the Cl^- in addition to the oxidant. The changes in concentration relative the concentration of Cl^- injected in the cell provide some clue to the location of DNAPL mass. The intermediate and lower extraction well profiles are similar to the injection feed profile suggesting that little mass removal is occurring in the

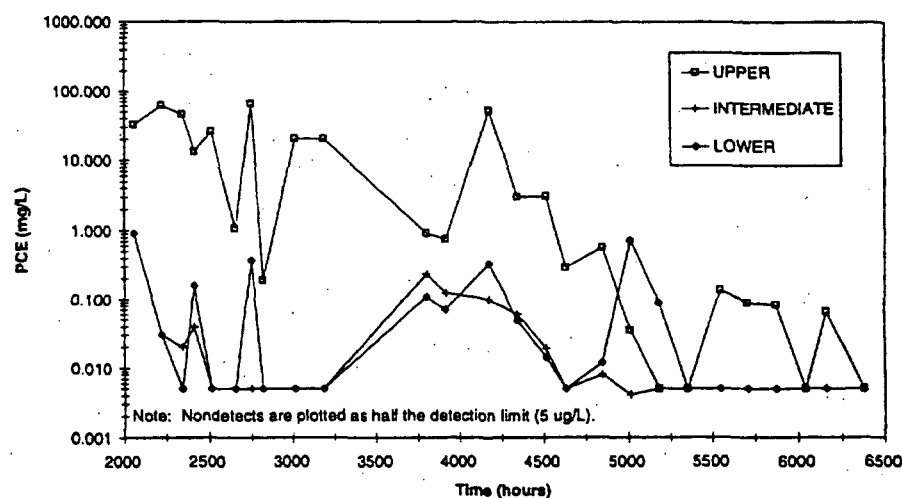


Fig. 10. Effluent PCE in the three pairs of extraction wells (highest relative concentrations in the upper pair).

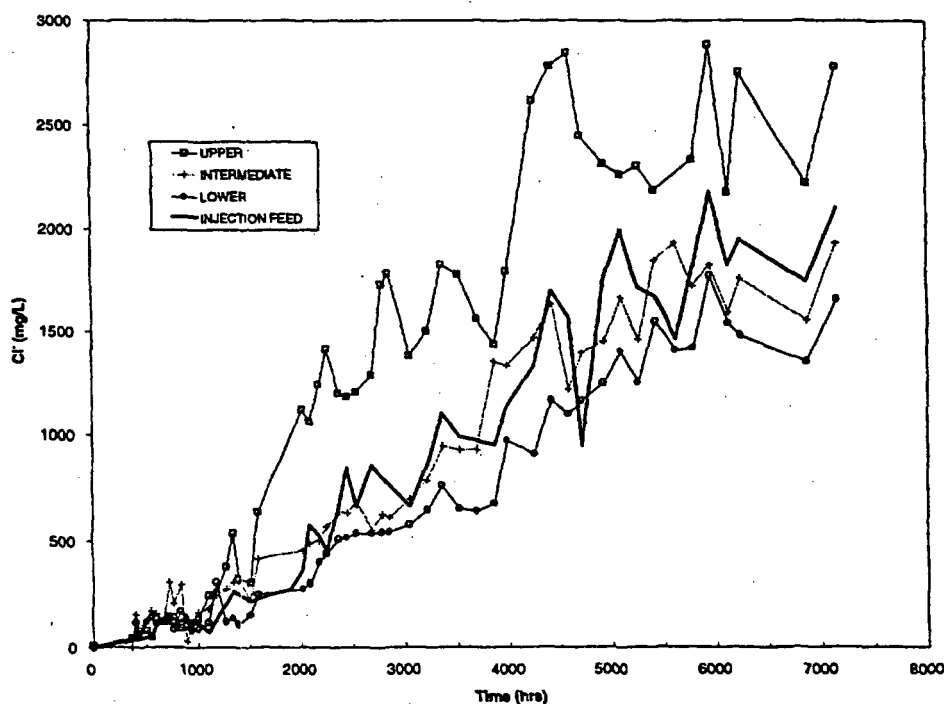


Fig. 11. Chloride concentrations observed in the extraction wells.

lower two thirds of the cell; however, up to the end of the oxidant flush, the Cl^- concentration in the upper extraction well is higher than the injection feed indicating that some solvent mass is still being oxidized.

8.4. Chloride mass balance

Mass balance calculations based on Cl^- production were used to estimate the extent of DNAPL oxidation. With a single pass system, such as that used in Experiment I, the concentration of Cl^- in the effluent from the extraction wells was readily converted to an equivalent mass of PCE oxidized. However, the recycle system used in Experiment II complicated the mass balance calculations because of the recycling of Cl^- back into the cell.

In addition, problems with the reinjection equipment during the initial stages of treatment resulted in periodic effluent losses from the system. It was estimated that 1.1 kg of Cl^- or 11% of the initial Cl^- mass was lost in this way.

An approximate method was used to estimate the mass of DNAPL oxidized based on Cl^- release. The averages of the last five effluent and the feed concentrations shown in Fig. 12 were assumed to represent the average Cl^- concentration in the entire cell. The total pore volume of the cell plus the liquid volume in the above ground treatment system, was estimated to be 2800 L. Based on this average, it was determined that

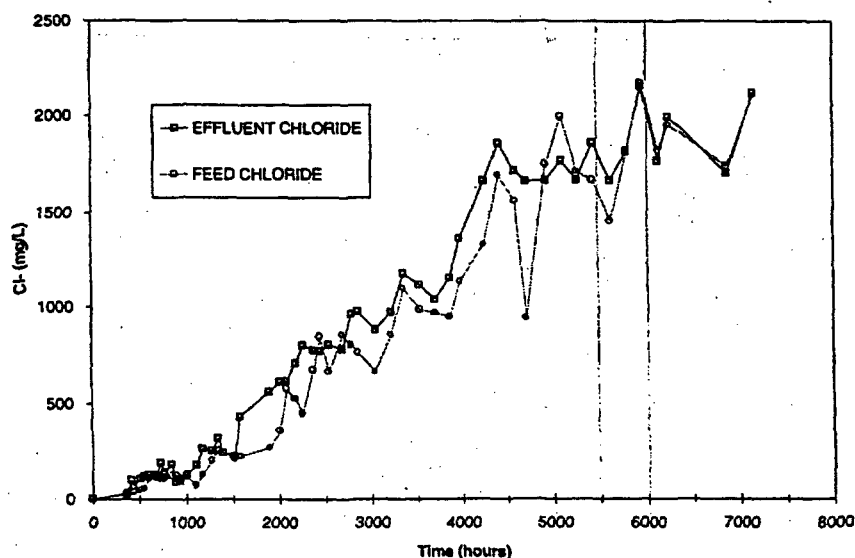


Fig. 12. Average effluent and injection feed chloride concentrations used to estimate total chloride mass in system.

approximately 51% of the Cl^- content of the original solvent source was present in this volume. Including the 11% Cl^- loss, approximately 62% of the initial mass of chlorine had been released by the oxidant flush.

9. Discussion

While in-situ oxidation removed substantial DNAPL mass in both field experiments, it is likely that the subsurface distribution of DNAPL had a significant effect on the rates of mass removal. In Experiment I, the residual PCE source was rapidly and completely oxidized, a reflection of the homogeneous distribution of the DNAPL as a residual with a relatively large surface area:volume (A:V) ratio which would allow rapid dissolution. As well, the aqueous phase permeability in the source area would be high relative to the permeability of source zones with high NAPL saturations. In more typical DNAPL sources, such as that used in Experiment II, non-wetting phase saturations would be highly variable and could possibly include pooled DNAPL above slight permeability contrasts. For example, in an experimental PCE release at a nearby location, PCE flow was found to be controlled by millimeter scale sand bedding structures with non-wetting phase saturations ranging from 1% to 38.1% (Kueper et al., 1993). Experiment II, containing a variable DNAPL distribution, would likely have some fraction of the solvent source present in both high and low saturations. The low saturations would be readily oxidized (as in Experiment I) but mass removal of high saturation zones would be slow owing both the lower aqueous phase permeability and lower A:V ratios. In the extreme case, where all the DNAPL is present as pools above low permeability zones

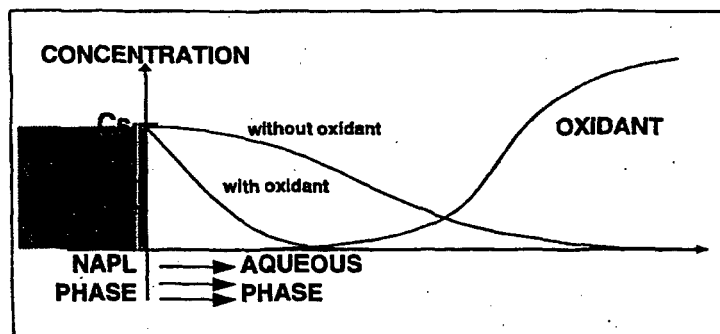


Fig. 13. Conceptual model describing mass removal by in-situ chemical oxidation.

and is occupying almost the entire pore space, mass removal would be limited by weak dispersive processes, resulting in lower mass removal from the source zone than achievable by advectively dominated flushing.

Successful prediction of overall rates of mass removal would require rate expressions for both non-equilibrium dissolution and oxidation. In the conceptual model (Fig. 13) proposed in this work to describe mass removal rates, dissolution mass transfer, driven primarily by aqueous phase PCE/TCE concentration gradients, is enhanced by the oxidation reaction which increases these gradients. As the aqueous solvent gradient is increased, the dissolution mass flux is increased. Simultaneously, the concentration gradient of the oxidant would be increased, causing an increase in oxidant mass flux towards the DNAPL:water interface.

The ability of in situ oxidation to remove PCE was clearly demonstrated in Experiment I. Based on the Cl^- mass balance, greater than 90% of the 1.64 kg emplaced mass was oxidized in 120 days; however, it was inferred from source sampling that 100% of the mass had actually been removed. The peak PCE concentration observed in the extraction wells at the beginning of this experiment prior to oxidation was 18 mg L^{-1} . Assuming that this effluent concentration remained constant, removal of the entire source by water flushing alone would require, at a minimum, 900 days. In agreement with the conceptual model of dissolution and oxidation as parallel kinetic processes, the oxidant flush was able to accelerate dissolution of this source by increasing the concentration gradients of both the dissolved phase solvent and the oxidant. It was evident from the Cl^- profiles that mass removal tailed off after the peak, an indication that mass transfer rates during the oxidant flush were decreasing as DNAPL mass was removed. This would suggest that the mass transfer rate expressions currently in the published literature (e.g. Powers et al., 1994; Geller and Hunt, 1993; Guiguer and Frind, 1994) might be applied to estimate dissolution mass transfer during an oxidant flush.

The release of Cl^- provided a measure of the spatial extent of source. During Experiment I, Cl^- production occurred only in the upper third of the cell zone and the treatment process was adjusted to limit flow to this area alone. In Experiment II, most of the oxidation again appeared to occur in the upper third of the cell based on the

extraction well Cl^- profiles. The Cl^- concentrations in the multilevel samplers generally supported this; however, the highest Cl^- concentrations were observed in MLC-5. This same multilevel contained pure phase during the entire experiment. These data suggest that during the DNAPL release at the beginning of the experiment, a portion of the solvent mixture moved laterally from the injection points, migrated down the multilevel stem and became immobilized at or below MLC-5. This is supported by other observations. During the experiment, Cl^- concentrations in the lower extraction wells, covering the vertical position of MLC-5, were only slightly different from the feed concentrations implying that little oxidation was occurring in the bottom third of the cell. This is consistent with the possibility of a small amount of DNAPL located right at the multilevel MLC 5 being oxidized to produce high localized Cl^- concentrations but only a small amount of Cl^- mass in the extraction wells. Short-circuiting down multilevel stems was also observed by Kueper et al. (1993).

Recycling of the oxidant was an effective method of reducing the amount of oxidant required and the degree of effluent treatment. Experiment I used approximately 80 kg of oxidant while Experiment II, with a substantially larger source mass, used almost 50 kg.

During Experimental I, it was expected that organic material and reduced mineral species in the Borden sand ($\text{foc} = 0.027\%$ w/w, Ball et al., 1990) would consume oxidant. The oxidant demand of the Borden sand in the cell was estimated, based on effluent KMnO_4 data (not shown) from Experiment I to be at most, $7 \text{ kg KMnO}_4 \text{ m}^{-3}$ Borden sand.

10. Application of in-situ oxidation at industrial sites

Experimentation with KMnO_4 has been limited to oxidation of TCE and PCE. While some other NAPL contaminants may be oxidizable (for example, other chlorinated alkenes), it is probable that many compounds will either be largely resistant to permanganate oxidation or oxidized to secondary organic compounds which may also be hazardous. This factor may make permanganate an unsuitable oxidant at field sites contaminated with solvent mixtures other than PCE and TCE. At field sites with complicated hydrogeology, the DNAPL source is likely to be spatially large with a complex distribution; a comprehensive site characterization program will be required to design of an injection system capable of supplying oxidant to the entire source while minimizing the volume of the treatment zone. At many sites, some DNAPL will be isolated from advective flow causing mass removal to be limited by diffusion of oxidant into that zone. In these zones, it is possible that mass removal by oxidation will be faster than technologies such as cosolvent/surfactant flushing, owing to the increased concentration gradients proposed in the conceptual model. In many cases, it may be that the application of in situ oxidation will rapidly remove the fraction of the DNAPL mass which has the largest driving potential for dissolution (large area to volume ratios in high permeability zones). Removal of this fraction could result in significant lowering of aqueous concentrations with only a modest reduction in DNAPL mass, which would be advantageous from both economic and risk based perspectives.

11. Summary and conclusions

Laboratory and pilot scale field experiments were performed to evaluate the effectiveness of KMnO_4 flushing as a means of DNAPL source removal through in-situ oxidation.

Column experimentation indicated that using the reaction product Cl^- was an effective means of following the progress of the oxidation reaction. Calculated mass balances based on Cl^- tended to overpredict mass removal; however, it was inferred from post-oxidation aqueous phase PCE concentrations that nearly complete removal of the PCE source was achieved. As well, mass removal was significantly faster and aqueous phase PCE concentrations were one to two orders of magnitude lower than with aqueous flushing alone.

Two field experiments were completed within a section of the CFB Borden aquifer isolated by double walled sheet piling. In each experiment, monitoring of the process was accomplished by measurements of Cl^- concentrations in multilevel piezometers and extraction wells. In Experiment I with a emplaced residual PCE source, the oxidant flush removed 100% of the DNAPL mass, as determined by aqueous phase concentrations, a chloride mass balance, and source zone core samples. In Experiment II, using a heterogeneous source produced by slowly leaking PCE and TCE into the field cell, about 60% of the DNAPL mass was removed from the source. Several factors appeared to control the effectiveness of in situ oxidation at the field scale. The process of dissolution is the principal determinant of DNAPL mass removal rates. It was clear that the rate of dissolution during an oxidant flush is much more rapid than during a water flush. Linked to the dissolution process is the distribution of the DNAPL and geologic heterogeneity. Complex distributions will require careful site characterization to design an effective oxidant injection system that is capable of delivering oxidant to the entire source zone.

Oxidant recycling was determined to be an effective and practical method of reducing both the total amount of oxidant required as well as the need for effluent treatment.

Chloride monitoring during each experiment was used to estimate the amount of mass destruction and also provided some indication of the location of the DNAPL.

The in situ oxidation technology has potential to be an effective means of removing DNAPL mass at rates much more rapid than conventional pump and treat strategies. It is unlikely that in-situ oxidation could ever remove 100% of the contaminant mass at an actual field site within a realistic time frame; however, it is feasible that rapid removal of the more accessible DNAPL will result in lower plume concentrations subsequent to the chemical flush and reduce the time required for a subsequent pump and treat system. Further work characterizing the dissolution process from various DNAPL distributions during an oxidant flush is presently ongoing to adequately address both these possibilities.

Acknowledgements

The authors are grateful for the support of the University Consortium on Solvents-in-Groundwater Research Program and its sponsors, including the Boeing Company,

Ciba-Geigy Corporation, Dow Chemical Canada/USA, Eastman Kodak Co., General Electric Co., Laidlaw Environmental Systems Ltd., Mitre Corporation, PPG Industries Corporation, and United Technologies Corporation. The efforts and insight of Neil Thomson are gratefully acknowledged. Additional funding was provided by the Ontario Ministry of Environment and Energy and the Natural Sciences and Engineering Research Council of Canada.

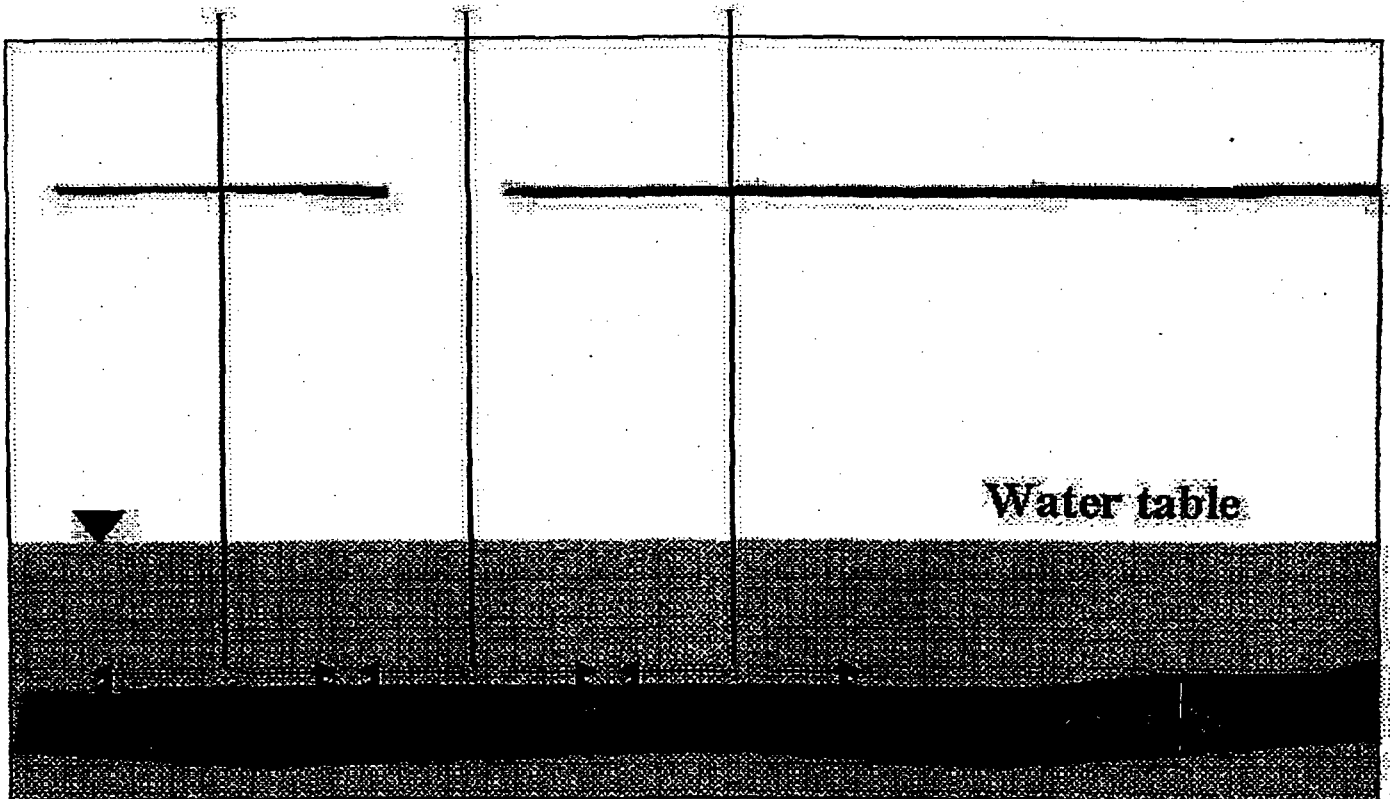
References

- Ball, W.P., Buehler, C.H., Harmon, T.C., MacKay, D.M. and Roberts, P.B., 1990. Characterization of a sandy aquifer material. *J. Contam. Hydrol.* 5, 253-295.
- Benefield, L.D., Judkins, J.F. and Weand, B.L., 1982. *Process Chemistry for Water and Wastewater Treatment*. Prentice-Hall, Englewood Cliffs, NJ.
- Bolha, J., 1986. Sedimentological investigation of progradational foreshore sequence: CFB Borden, M.Sc. Dissertation, School of Earth Sciences, University of Waterloo, Ontario.
- Cho, S.H. and Bowers, A.R., 1991. Treatment of toxic or refractory aromatic compounds by chemical oxidants. In: R.E. Hincee and R.F. Olfenbuttel (Editors). *On-site Bioreclamation Processes for Xenobiotic and Hydrocarbon Treatment*. Butterworth-Heinemann, Boston, MA, pp. 255-260.
- Colthurst, J.M. and Singer, P.C., 1982. Removing trihalomethane precursors by permanganate oxidation and manganese dioxide precipitation. *J. AWWA*, February: 78-83.
- Cowie, A.M. and Weider, M.F., 1986. In situ remediation of formalin release at Monsanto, Springfield, Massachusetts. *Proc. Hazardous Material Spills Conf.*, pp. 255-260.
- Doty, C.B. and Travis, C.C., 1991. The effectiveness of groundwater pumping as a restoration technology. ORNL/TM-11866, Oak Ridge National Laboratory, Oak Ridge, TN.
- Eilbeck, W.J. and Mattock, G., 1987. *Chemical Processes in Wastewater Treatment*. John Wiley and Sons, Toronto, Ontario.
- Geller, J.T. and Hunt, J.R., 1993. Mass transfer for nonaqueous phase organic liquids in water-saturated porous media. *Water Resour. Res.* 29, 911-924.
- Guiguer, N. and Frind, E.O., 1994. Dissolution and mass transfer for residual organics in the groundwater zone. In: T.H. Dracos and F. Stauffer (Editors). *Proc. IAHR/AIRH Symp. on Transport and Reactive Processes in Aquifers*, Zurich, Switzerland, pp. 475-480.
- Johnson, R.L. and Pankow, J.F., 1992. Dissolution of dense chlorinated solvents into groundwater. 2. source functions for pools of solvent. *Environ. Sci. Technol.* 26 (2), 896-901.
- Kueper, B.H., Redman, D., Starr, R.C., Reitsma, S. and Mah, M., 1993. A field experiment to study the behaviour of tetrachloroethylene below the water table: spatial distribution of residual and pooled DNAPL. *Ground Water* 31 (5), 756-766.
- Lee, D.G., 1980. *The Oxidation of Organic Compounds by Permanganate Ion and Hexavalent Chromium*. Open Court Publishing Company, LaSalle, Illinois.
- Mackay, D.M. and Cherry, J.A., 1989. Groundwater contamination: pump and treat remediation. *Environ. Sci. Technol.* 23 (6), 630-636.
- National Research Council, 1994. *Alternatives for Groundwater Cleanup*. National Academy Press, Washington, DC.
- Pankow, J.F. and Cherry, J.A., 1996. *Dense Chlorinated Solvents and Other DNAPLS in Groundwater: History, Behaviour, and Remediation*. Waterloo Press, Portland, Oregon.
- Perry, R.H., Green, D.G. and Maloney, T.O. (Editors), 1984. *Perry's Chemical Engineer's Handbook*. McGraw-Hill, Toronto, Ontario.
- Plumb, R.H., 1991. The occurrence of appendix IX organic constituents in disposal site groundwater. *Ground Water Monitoring Review*, Spring, pp. 157-165.
- Poulsen, M.M. and Kueper, B.H., 1992. A field experiment to study the behaviour of tetrachloroethylene in unsaturated porous media. *Environ. Sci. Technol.* 26 (5), 889-895.

- Powers, S.E., Abriola, L.M., Dunkin, J.S. and Weber, W.J., 1994. Phenomenological models for transient NAPL–water mass transfer process. *J. Contam. Hydrol.* 16, 1–33.
- Smith, J., 1990. Groundwater quality in California: overview and implications. *Proc. 17th Biennial Conf. on Groundwater*, University of California Water Resources Centre, pp. 93–107.
- Starr, R., Cherry, J., Vales, S., Smyth, D. and Jowett, C., 1992. Development of sealable-joint sheet pile cut-off walls for groundwater remediation. *Proc. Environmental Research and Technology Conference*, Ontario Ministry of the Environment and Energy, Nov. 5–6, Toronto, Ontario.
- Steel, E.W. and McGhee, T.J., 1979. *Water Supply and Sewerage*, Fifth Edition. McGraw-Hill, New York, NY.
- Stewart, R., 1965. In: K. Wiberg (Editor). *Oxidation in Organic Chemistry: Oxidation by Permanganate*. Academic Press, New York, NY.
- Sudicky, E.A., 1986. A natural gradient experiment on solute transport in a sand aquifer: spatial variability of hydraulic conductivity and its role in the dispersion process. *J. Contam. Hydrol.*, 13: 2069–2083.
- Vella, P.A. and Veronda, B., 1992. Oxidation of trichloroethylene: a comparison of potassium permanganate and fenton's reagent. Presented at the Third Int. Symp. on Chemical Oxidation Technology for the Nineties, Vanderbilt University, Nashville, TN.
- Vella, P.A., Deshinsky, G., Eoll, J.E., Munder, J. and Joyce, W.M., 1990. Treatment of low level phenols with potassium permanganate. *Res. Jour. WPCF* 62 (7), 907–914.
- Westrick, J.J., Mello, J.W. and Thomas, R.F., 1984. The groundwater supply survey. *J. AWWA*, May, 52–59.

Final Report
for
Demonstration of In Situ Oxidation of DNAPL
Using the Geo-Cleanse® Technology

RECEIVED
DEC 09 1997
OSTI



dy
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

400276

37E03F

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

Final Report
for
Demonstration of In Situ Oxidation of DNAPL
Using the Geo-Cleanse® Technology

U.S Department of Energy Office of Technology Development
U.S. Department of Energy Savannah River Operations

Prepared by:
Karen M. Jerome
Brian Riha
Brian B. Looney

U.S. Department of Energy
Westinghouse Savannah River Company
Savannah River Technology Center

Savannah River Site
Aiken, SC 29808

operated by :

Westinghouse Savannah River Company
for the U.S. Department of Energy under Contract No. DE-AC09-96-SR18500

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

TABLE OF CONTENTS

| | |
|---|----|
| 1.0 SUMMARY | 1 |
| 2.0 INTRODUCTION | 2 |
| 3.0 BACKGROUND | 2 |
| 4.0 TECHNICAL BASIS | 3 |
| 4.1 Fenton's Chemistry | 3 |
| 4.2 Description of Geo-Cleanse® Technology | 5 |
| 4.3 Green Clay Integrity in the Vicinity of the M-Area Basin | 6 |
| 4.4 Selection of Demonstration Location | 6 |
| 5.0 DESCRIPTION OF DEMONSTRATION | 6 |
| 6.0 ANALYSIS AND EVALUATION OF PRE-TEST CHARACTERIZATION SAMPLES | 9 |
| 7.0 ANALYSIS AND EVALUATION OF TREATMENT TEST SAMPLES | 10 |
| 8.0 ANALYSIS AND EVALUATION OF POST-TEST CHARACTERIZATION SAMPLES | 10 |
| 9.0 EVALUATION OF DEMONSTRATION SUCCESS | 12 |
| 10.0 COST EVALUATION OF DEMONSTRATION | 16 |
| 10.1 Overall Cost of Demonstration in Relationship to Sensitivity to each Component of Demonstration | 16 |
| 10.2 Unit Cost of In Situ Oxidation Technology | 18 |
| 11.0 DISCUSSION OF RESULTS | 22 |
| 12.0 REFERENCES | 23 |

LIST OF TABLES

| | | |
|------------|--|----|
| Table 9.1 | Pre- and Post-Test DNAPL Mass and Destruction Efficiency for the In Situ Oxidation Demonstrations | 12 |
| Table 10.1 | Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Activity Category | 16 |
| Table 10.2 | Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Task | 17 |
| Table 10.3 | Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a Function of Depth to Contamination | 20 |

LIST OF FIGURES

| | | |
|-------------|--|----|
| Figure 3.1 | Area Map of In Situ Oxidation Demonstration Site, Located Adjacent to the M- Area Hazardous Waste Management Facility | 4 |
| Figure 4.1 | Map of Green Clay in the Vicinity of the In Situ Oxidation Demonstration Site | 7 |
| Figure 5.1 | Schematic of In Situ Oxidation Field Demonstration Site Layout | 8 |
| Figure 7.1 | In Situ Oxidation Treatment Period Data | 11 |
| Figure 9.1 | Pre- and Post- Test Sediment Concentrations for the In Situ Oxidation Demonstration | 13 |
| Figure 9.2 | Pre- and Post- Test DNAPL Mass for the In Situ Oxidation Demonstration | 14 |
| Figure 9.3 | Monitoring Well Data Showing Rebound of Contaminant Concentrations for In Situ Oxidation Demonstration | 15 |
| Figure 9.4 | Chloride Ion Concentration for In Situ Oxidation Demonstration | 16 |
| Figure 10.1 | Full Scale Representation of Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a function of Depth to Contamination | 21 |
| Figure 10.2 | Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a function of Depth to Contamination | 22 |

APPENDICES

| | |
|-------------------------|---|
| APPENDIX A | RAW DATA, SOIL CONCENTRATION DEPTH PROFILES FOR IN SITU OXIDATION DEMONSTRATION, AND CALCULATION OF DNAPL VOLUME |
| APPENDIX B..... | SAMPLING AND ANALYSIS METHODS |
| APPENDIX C | BASIS FOR UNIT COST FOR PUMP AND TREAT SYSTEM |
| APPENDIX D | UNIT COST CALCULATION FOR IN SITU OXIDATION TECHNOLOGY |

ACRONYM LIST

| | |
|-------------|--|
| bgs | below ground surface |
| cfm | cubic feet per minute |
| DNAPL | Dense Non-Aqueous Phase Liquid |
| ECD | Electron Capture Detector |
| FID | Flame Ionization Detector |
| ft | feet |
| GC | Gas Chromatograph |
| GC-MS | Gas Chromatograph - Mass Spectrometer |
| gm | gram |
| µgm | microgram |
| lb | pound |
| LNAPL | Light Non-Aqueous Phase Liquid |
| mg/L | milligrams/liter |
| MOX and MSB | Well identifier series |
| msl | mean sea level |
| NAPL | Non-Aqueous Phase Liquid |
| PCB | Polychlorinated Bi-Phenyl |
| PCE | Perchloroethylene or tetrachloroethylene |
| ppm | parts per million |
| ppmv | parts per million-vapor |
| RCRA | Resource Conservation and Recovery Act |
| SRS | Savannah River Site |
| SVE | Soil Vapor Extraction |
| TCE | Trichloroethylene |

Chemicals

| | |
|-------------------------------|-------------------|
| CO ₂ | carbon dioxide |
| Cl | chloride ion |
| Fe+2 | ferrous iron |
| Fe+3 | ferric iron |
| H ₂ O ₂ | hydrogen peroxide |
| OH- or OH* | hydroxyl radical |
| H ₂ O | water |

1.0 SUMMARY

At large industrial sites like the A/M Area of the Savannah River Site (SRS), undissolved dense non-aqueous phase liquid (DNAPL) in soil and groundwater is the most significant barrier to successful clean up. DNAPL acts as a reservoir that will continue to generate contaminant levels far above remediation concentration goals well into the future. In an effort to achieve remediation goals and reduce future costs, the SRS DNAPL program is evaluating technologies which will recycle or destroy DNAPL. In situ oxidation is one class of DNAPL destruction technologies. A demonstration of this technology was conducted at SRS in the spring of 1997. This demonstration involved treating a small DNAPL plume in the A/M Area over a 6 day period. A destruction efficiency of 94 % was achieved in this small scale test. As part of the test evaluation, a unit cost per pound of DNAPL was determined for different depths to DNAPL and for varying volumes of DNAPL. Comparison was made to pump and treat (air stripping) which is considered a baseline technology for DNAPL contaminated groundwater. This information will provide a basis to determine which DNAPL contaminated waste units will be remediated in a more cost effective manner by using in situ oxidation. For the A/M Area, a DNAPL pool of approximately 11,000 pounds or more is required for this technology to be more cost efficient than pump and treat.

The in situ oxidation of DNAPL demonstration deployed a technology based on Fenton's chemistry to destroy DNAPL below the water table. This demonstration was a cooperative venture between Westinghouse Savannah River Company and Geo-Cleanse International, Inc. The site selected for the demonstration is a 50 ft by 50 ft area adjacent to the M-Area Seepage Basin, a known source of DNAPL. The site is located along an area of DNAPL migration in the subsurface. DNAPL is located at approximately 140 ft below surface at the demonstration site (approximately 20 ft below the top of the water table). The treatment zone consisted of a 64,000 ft³ volume of soil containing approximately 600 pounds of DNAPL. Four injector wells, three monitoring wells and three vadose zone piezometers were installed for this test. The demonstration occurred in three stages: pre-test characterization, technology test, and post-test characterization.

Characterization efforts conducted throughout the demonstration were used to evaluate the effectiveness of the technology. Pre- and post-test characterization activities consisted primarily of soil core sampling to determine the soil concentration of TCE and PCE in the treatment zone. Groundwater sampling was conducted throughout all three phases of the demonstration to provide information on TCE and PCE concentrations, chloride concentrations, pH and temperature. Indicators of destruction include increase in chloride concentration in groundwater during the treatment period and decreases in TCE and PCE concentration in both groundwater and soil from pre-test to post-test.

Field activities were initiated January 8, 1997 with the start of pre-test characterization of the demonstration site. These activities lasted for five weeks. Infrastructure support activities were completed and the demonstration test was initiated on April 15, 1997. The six day treatment period ended on April 21, 1997. The treatment period lasted for six days. Post-test characterization activities began April 24, 1997 and were completed July 23, 1997.

Several observations made during the treatment period have led to a proposal for follow-on work. Increased groundwater temperature, inoperable groundwater monitoring pumps during operation (due to release of gases from reaction) and audible bubbling sounds from the monitoring wells indicated a vigorous chemical reaction occurred. This raised questions on what happens in the treatment zone from a geo-chemical and biological perspective.

2.0 INTRODUCTION

The in situ oxidation of DNAPL demonstration deployed a technology based on Fenton's chemistry to destroy DNAPL below the water table. This demonstration, sponsored by the Department of Energy, is a cooperative venture between Westinghouse Savannah River Company and Geo-Cleanse International, Inc. (referred to as Geo-Cleanse through the remainder of this document). The purpose of this demonstration is to evaluate a technology in the general class of DNAPL destruction technologies. The site selected for the demonstration is a 50 ft by 50 ft area adjacent to the M-Area Seepage Basin, a known source of DNAPL. The site is located along an area of DNAPL migration in the subsurface. DNAPL is located at in a thin zone at approximately 140 feet below surface (and in discrete lenses associated with other clay layers at the site) at the demonstration site. Four injector wells, three monitoring wells and three vadose zone piezometers were installed for this test. The demonstration occurred in three stages: pre-test characterization, technology test, and post-test characterization. The following report documents results and conclusions of this demonstration.

Field activities were initiated January 8, 1997 with the start of pre-test characterization of the demonstration site. These activities lasted for five weeks. Infrastructure support activities were completed and the demonstration test was initiated on April 15, 1997 with completion on April 21, 1997. The treatment period lasted for six days. Post-test characterization activities began April 24, 1997 and were completed July 23, 1997.

3.0 BACKGROUND

The M-Area of Savannah River Site was a fuel and target fabrication facility. The mission of this area was processing uranium, lithium, aluminum and other materials into fuel elements and targets for use in the nuclear production reactors. The processes were primarily metallurgical and mechanical, such as casting, extrusion, plating, hot-die-sizing, welding and magneforming. Solvent cleaning and acid/caustic etching were used to prepare the materials.

The M-Area Settling Basin and associated areas (the overflow ditch, Lost Lake, the seepage area, and the inlet process sewer line), designated as the M-Area Hazardous Waste Management Facility, received process effluent from 1958 until 1985. VOC contamination of soils and groundwater occurred in M-Area as a result of breaks in the old process-sewer line and disposal to the basin. In 1985, pump and treat was employed, followed by soil vapor extraction (SVE) in 1995. The M-Area Settling Basin, capped in 1988 and closed under RCRA, is a certified closure as a landfill. These activities have been performed under a RCRA Post Closure Care Part B Permit. This demonstration of an in situ oxidation technology to destroy DNAPL supports the phased remediation of the 1500 acre plume.

A wide range of research and development activities have been performed in support of the A/M -Area groundwater corrective action. These various activities have been designated the Integrated Demonstration and include use of horizontal wells for remediation, an in situ air stripping test, in situ bioremediation test, off gas treatment technology tests, a radio frequency heating test, and an ohmic heating test. Development and demonstration of characterization tools have also been an integral part of the program in the A/M area.

During routine sampling using a bottom filling bailer, a separate, dense phase was identified in monitoring wells MSB-3D and MSB-22 sumps. These wells are located approximately 20 feet from the M-Area Settling Basin. The relatively thick vadose zone, approximately 130 ft, beneath A/M-Area tends to limit the downward flux of DNAPL and capture some DNAPL in layered clays. As expected, DNAPL below the water table has been observed where solvent release exceeded the capacity of the vadose zone to moderate the flux of the pure phase to the groundwater. The clearest evidence of DNAPL below the water table was found at the Settling Basin, where a separate phase was identified in the sumps of wells MSB-3D and MSB-22. Data collected at separate times suggest that DNAPL below the water table occurs as

relatively diffuse ganglia and/or a thin layer on the top of aquitards, and that DNAPL collects in well sumps as a result of dynamic processes. One such process is accumulation of dense ganglia in the well sump as the well is actively purged and sampled (similar to accumulation of sediments in the sump).

The cone penetrometer, in conjunction with conventional coring, allowed refinement of the delineation of an important clay zone (the "green clay") beneath the water table. Undulations and other structural variations on top of this layer serve to control movement of a dense phase below the water table. Based on cone penetrometer results, structure controlled pathways for density-dominated transport below the water table were discerned. Two potential pathways were identified. The primary potential pathway of contaminant migration begins near the Settling Basin, where DNAPL was found in monitoring wells MSB-3D and MSB-22, Figure 3.1. The contour grades toward the west and then north toward MSB-76, where high dissolved constituent concentrations ($> 1000\mu\text{g/L}$) are reported.

Phase I of the DNAPL characterization provided significant insight into the nature and location of DNAPL in the SRS subsurface. In particular, data indicate a substantial amount of DNAPL has been trapped in clays and silts in the vadose zone above the water table. Phase I characterization data also suggest DNAPL below the water table in A/M-Area is present as disconnected ganglia, rather than as a large, solvent-saturated layer. DNAPL present below the water table is composed of approximately 95% TCE, 5% PCE and a very small but measurable amount of PCBs. Objectives of Phase 2 of the DNAPL remediation focus on: (1) pure phase DNAPL, (2) recycle of DNAPL, and (3) on site destruction of DNAPL.

The in situ oxidation of DNAPL demonstration is an important element of the Phase 2 remediation activities. This demonstration involves in situ oxidative destruction of the DNAPL plume using Fenton's chemistry. Demonstration activities were conducted within one quarter mile of the M-Area Settling Basin. Figure 3.1 shows the selected location for this demonstration, the area of review, all monitoring wells, surface bodies of water, roads, and other cultural features. Because "treatment" of pure phase non-aqueous phase liquid (NAPL) is the key to a successful and timely cleanup, in situ oxidation technologies are promising systems for destruction of both aqueous and pure phase NAPL in the subsurface.

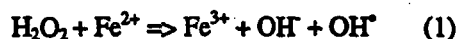
4.0 TECHNICAL BASIS

4.1 Fenton's Chemistry

The Geo-Cleanse® process is an in situ oxidative reduction process based on Fenton's chemistry.

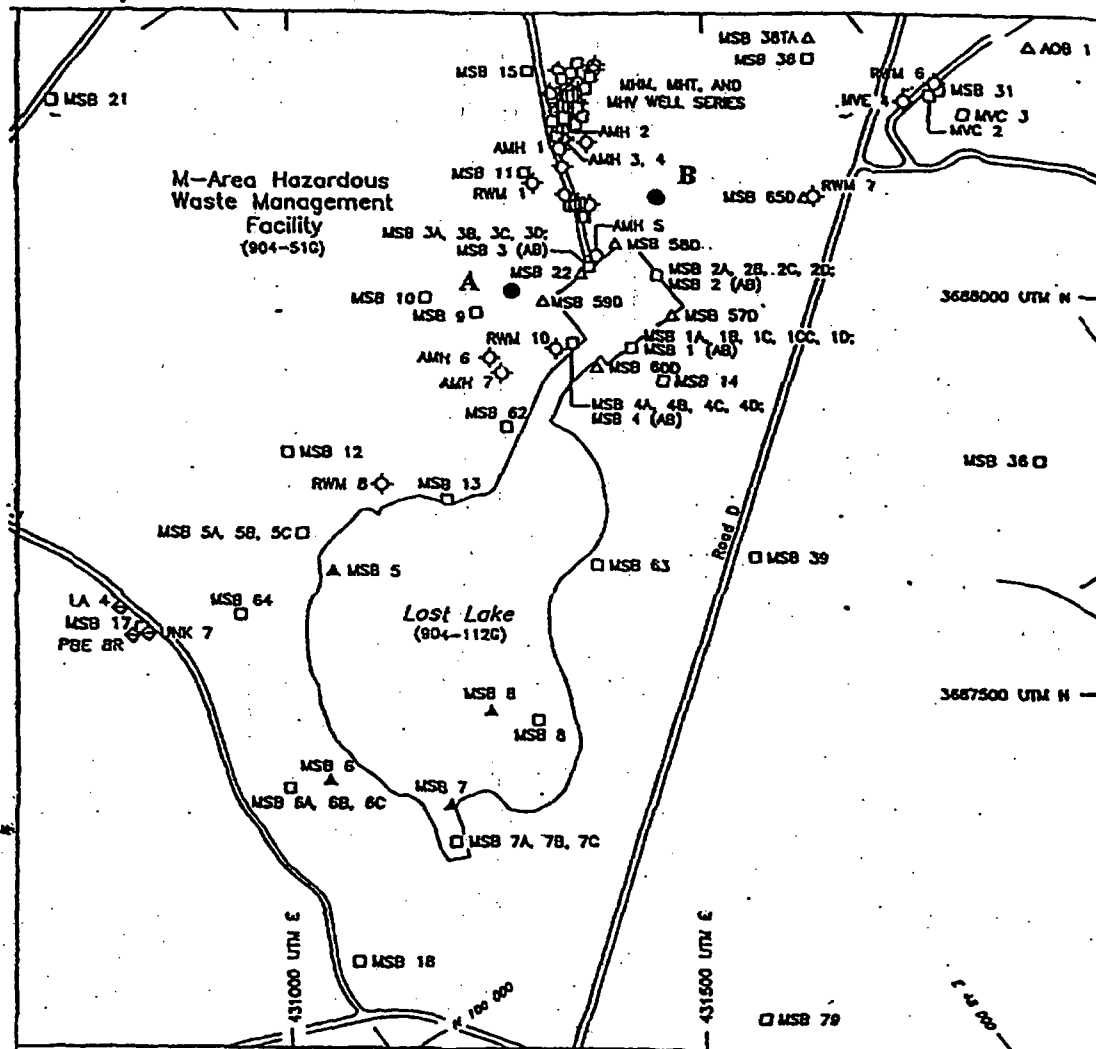
H. J. H. Fenton developed a chemistry which oxidized malic acid through use of hydrogen peroxide and iron salts in the 1890s. This chemistry has been, and is still widely used by the waste water industry for treatment of organic wastes. Hydrogen peroxide is the active ingredient in oxidation of organic compounds by this methodology. The hydroxyl radical is the reactive species in this process.

The chemistry of Fenton's reagent (1) is well documented as a method for producing hydroxyl radicals by reaction of hydrogen peroxide and ferrous iron (Fe^{+2}). Hydroxyl radicals are very powerful, effective and nonspecific oxidizing agents, approximately 10^6 to 10^9 times more powerful than oxygen or ozone alone.



With the Geo-Cleanse® process, iron salts in the form of ferrous sulfate (Fe^{+2}) and hydrogen peroxide are injected with a patented process, Patents #5,525,008 and #5,611,642, to generate hydroxyl radicals. Proprietary mixtures of non-hazardous metallic salts are used to control the reaction. During the optimum reaction sequence and when the catalyst is iron, ferrous iron (Fe^{+2}) is converted to ferric iron (Fe^{+3}). Ferrous iron is soluble in water at the target pH and is necessary for generation of the hydroxyl radical,

but ferric iron will not generate the hydroxyl radical and is less soluble at the target pH range (pH 5 to 6). However, under properly controlled and buffered conditions, ferric iron can be regenerated back to ferrous iron by a subsequent reaction with another molecule of hydrogen peroxide (2).

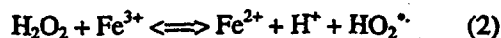


A and B were proposed locations for demonstration.

A is location of In Situ Oxidation Demonstration.

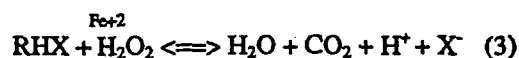
Figure 3.1

Area Map of In Situ Oxidation Demonstration Site, Located Adjacent to the M-Area Hazardous Waste Management Facility



In this case, the iron will remain available in ferrous form as long as pH is properly buffered and there is sufficient hydrogen peroxide. As hydrogen peroxide is consumed, some iron will precipitate out as ferric iron (if pH is moderate). The Geo-Cleanse® process has been widely used for light non-aqueous phase liquids (LNAPLs), and adverse impacts due to precipitation of iron have not been observed.

There are many reactions that occur during the oxidation of a contaminant, but as shown by equation (3) a contaminant (RHX), hydrogen peroxide, and ferric iron, as a catalyst, are consumed to produce water and carbon dioxide. RHX represents an organic compound and X represent a halide (such as chloride). If the compound is non-halogenated (no X), then the hydrogen ion and halide anion are not formed in the *overall* reaction. Thus compounds such as BTEX are converted to carbon dioxide and water, whereas trichloroethylene and tetrachloroethylene are converted to carbon dioxide, water, hydrogen and chloride ions, which are all non-toxic at the levels they will be produced.



4.2 Description of Geo-Cleanse® Technology

Geo-Cleanse® technology, an in situ destruction technique, utilizes Fenton's reagent (ferrous iron and hydrogen peroxide) to convert organic contaminants to water and carbon dioxide. Hydrogen peroxide and catalyst (ferrous sulfate and/or sulfuric acid) are injected into the groundwater zone where DNAPL contamination is located. A patented injection process is used to inject hydrogen peroxide and catalyst.

After initial characterization of the site and installation of injectors in the zone of contamination, the treatment process is initiated. The number of injectors installed and volume of injectate is based on the source area size. Injection of catalyst solution with 2 to 4 cfm of air to sparge the catalyst away from the injector into the formation is the initial step in treatment. This adjusts the groundwater pH to between 4 and 6, where metals, specifically iron, will be at the optimal electron state, +2. This is followed by the simultaneous injection of hydrogen peroxide and catalyst. Mixing of catalyst and hydrogen peroxide in the subsurface will generate heat as the reaction with organic contaminants progresses. Monitoring is conducted during the treatment phase for water vapor, carbon dioxide gas, hydrogen peroxide, the contaminants to be destroyed, pH, conductivity, and dissolved oxygen. Catalyst solution may be added throughout the injection process to maintain groundwater pH within the range of 4 to 6.

A key part of this technology is the injection process. The injection process is proprietary and Patents #5,525,008 and #5,611,642 have been issued. The injector contains a mixing head which is utilized for mixing reagents and has components to stimulate circulation of groundwater to promote rapid reagent diffusion and dispersion. Thus, all reagents are injected into the subsurface through the injectors. Upon start of the injection process, air with catalyst solution is injected to ensure the injector is open to the formation prior to injection of peroxide and catalyst solution. When an acceptable flow has been established, peroxide and catalyst will be injected simultaneously. This ensures that catalyst and peroxide will not mix together in the sealed system. The injector is designed with a check valve and constant pressure delivery system which prevents mixing of the chemicals before they have reached the zone of contamination/treatment. Thus, the chance of reaction within the wellbore is eliminated.

4.3 Green Clay Integrity in the Vicinity of the M-Area Basin

Typical of the Atlantic Coastal Plain, sediments beneath A/M-Area are interbedded sands, silts and clays deposited during periods of fluctuation in sea level and modified by erosion during intervening times. Clay rich confining, or restrictive, intervals are interspersed with more transmissive, sandier intervals. In A/M-Area, there are several clay rich intervals above the water table (with elevations of about 325 feet msl, 305 feet msl, and 270 feet msl). Ground surface in central A/M-Area is about 365 feet msl, and the water table is approximately 135 feet deep (elevation 235 feet msl). DNAPL below the water table (target contamination for this in situ oxidation test) accumulates in sandy layers on top of fine grain (clay and silt) layers. The uppermost significant clay beneath the water table is termed the "Green Clay." This confining zone is at an elevation of approximately 200 feet msl (or about 35 feet below the water table). The structural contour of this layer was carefully delineated in previous characterization work (WSRC, 1992). Delineation indicated the Green Clay is generally present in the vicinity of the M-Area Settling Basin. The uppermost surface of the Green Clay is not flat, but has structural features, undulating or irregular features forming local depressional or trough-like areas that control migration of DNAPL near the basin. Data from A/M-Area indicate discontinuities, in the form of compositional changes, present in the Green Clay. Note, however, that the scale and pattern of DNAPL migration (in a narrow structural feature located between the M-Area Settling Basin and well cluster MSB 76) indicate DNAPL accumulated above the Green Clay; this is a target of opportunity for in situ destruction technologies. Figure 4.1 is a representation of the surface contour of the Green Clay in the vicinity of the M-Area Settling Basin. It is based on cone penetrometer data and hydrostratigraphic core information collected in the general vicinity of the M-Area Settling Basin and Integrated Demonstration Site.

4.4 Selection of Demonstration Location

Two locations of suspected DNAPL accumulation were identified adjacent to the closed M-Area Settling Basin, see Figure 3.1. Location A, the location chosen for the demonstration, is approximately 50 yards off the western corner of the basin. This location is in a bowl shaped surface depression approximately 50 feet square. It is located within a suspected subsurface trough in the Green Clay along which DNAPL is migrating. The second location is off the eastern corner of the basin, location B in Figure 3.1. Soil sample data showed no DNAPL, TCE and PCE below the water table at location B.. TCE and PCE were detected at a single depth in the vadose zone at location B. Concentrations of 0.98 µg TCE/gm of soil and 4.5 µg PCE/gm of soil were detected at an approximate depth of 90 feet below ground surface.

Initial field work for this demonstration involved continuously coring and collecting samples in both locations to determine the preferred site. One boring was drilled at each location. The location with the greatest concentration of TCE and PCE was selected for this demonstration. Site A was the chosen location. The estimated pre-tested volume of DNAPL at this location was approximately 600 pounds.

5.0 DESCRIPTION OF DEMONSTRATION

This demonstration was conducted in three phases: pre-test characterization, technology test (or treatment phase), post-test characterization. Pre-test characterization was used to identify the location of the demonstration, the zone below the water table to be targeted for treatment, and initial TCE and PCE concentrations. Pre-test drilling consisted of 2 initial borings, located off the west corner and off the east corner of the basin, followed by 6 borings at the site selected for the demonstration. The locations of the pre-test borings at the selected test site are identified as MOX-1 through MOX-8, as shown in Figure 5.1. These locations were all cored and samples collected and analyzed for TCE and PCE concentrations. MOX-1 through MOX-4 were completed as injection wells and MOX-5 through MOX-8 were completed as monitoring wells. (MOX-6 is the identifier of the second of the two initial borings drilled to select the demonstration location.) In addition, 4 vadose zone piezometers, identified as MOX-1V through MOX-4V, were installed. No characterization data was collected during the installation of the piezometers. The treatment phase involved injection of the chemicals required for the destruction reaction to occur.

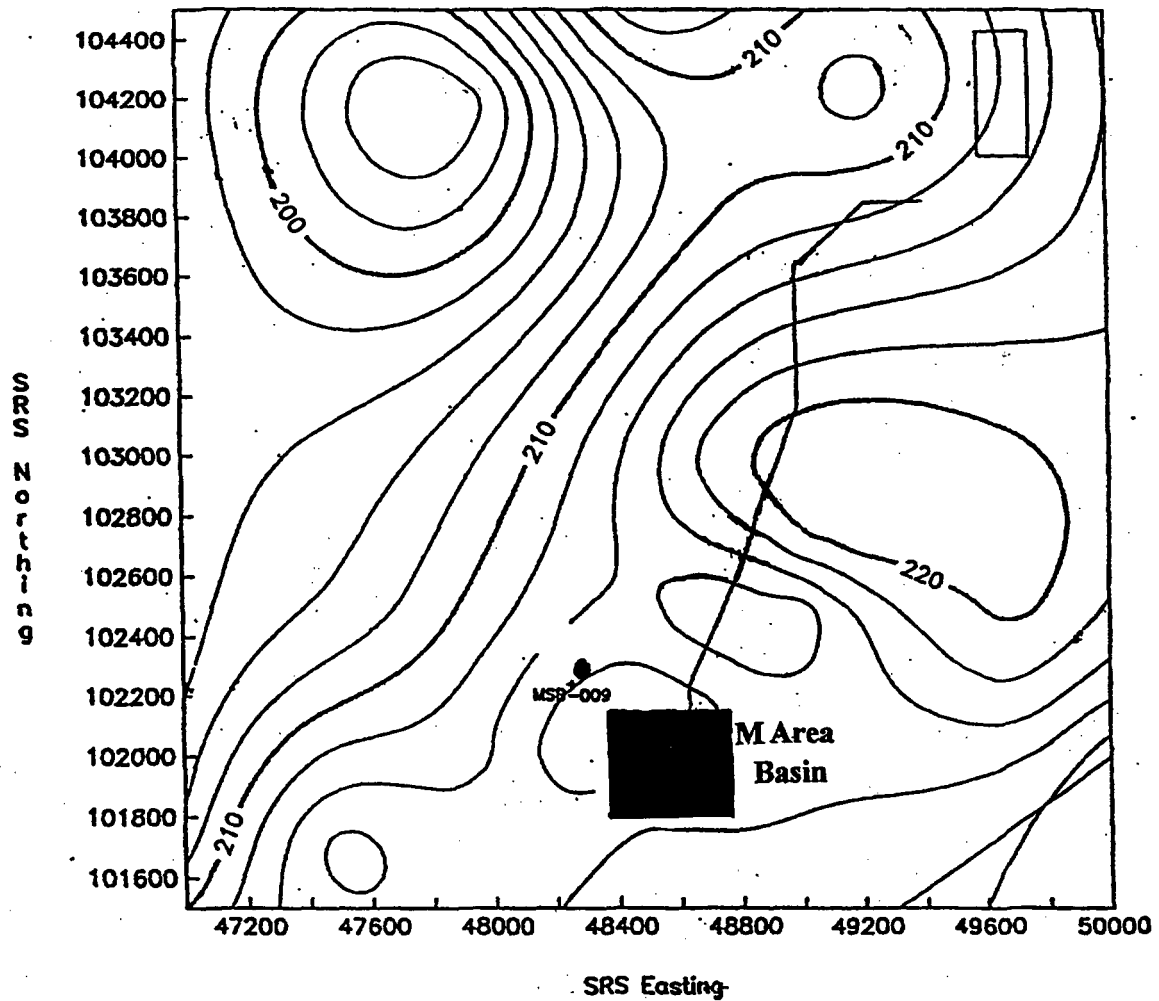


Figure 4.1
Site

Map of Surface of the Green Clay in Vicinity of the In Situ Oxidation Demonstration

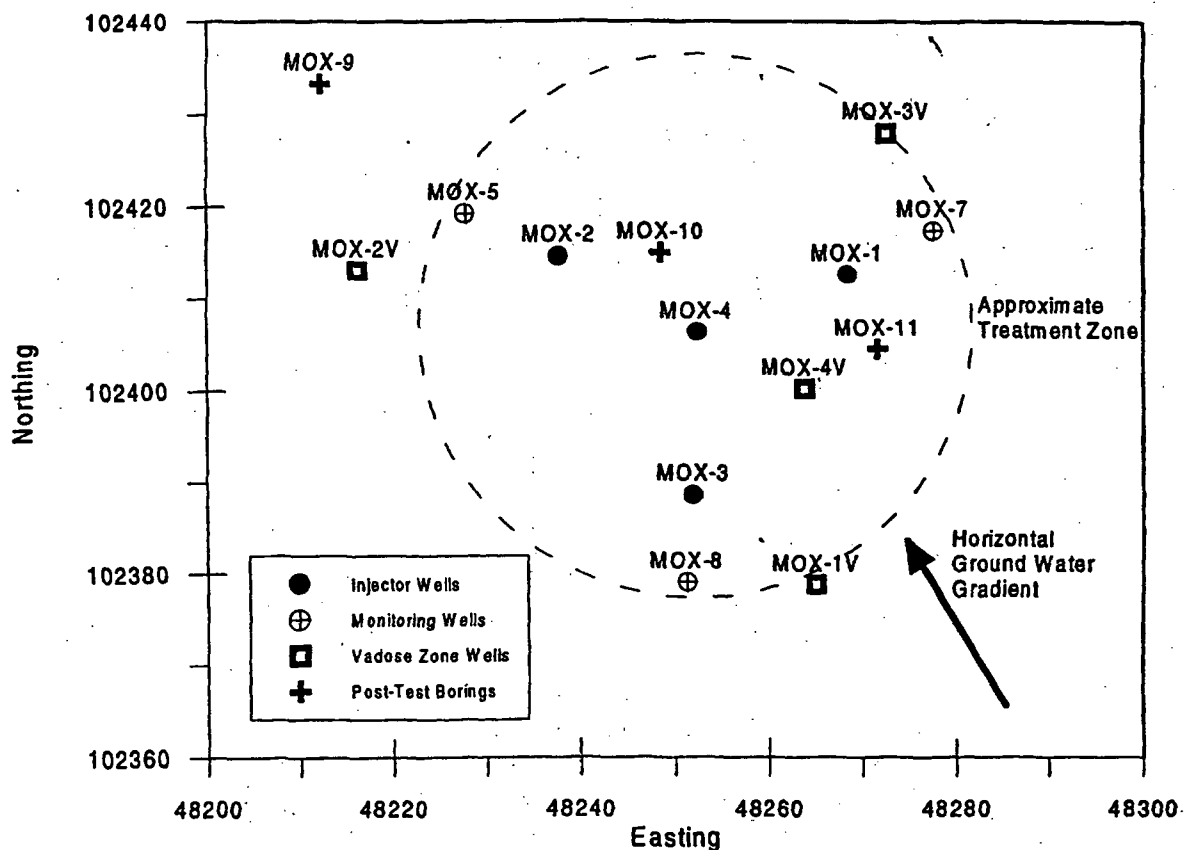


Figure 5.1 Schematic of In Situ Oxidation Field Demonstration Site Layout (coordinates are a local grid in feet)

Injection occurred over a six day period, in a batch process mode of approximately 6 hours per day, completing one batch per day. The process was initiated each day by injection of the catalyst solution. This was followed by injecting peroxide and additional catalyst, simultaneously, in volumes varying from 500 to 1000 gallons per batch. Monitoring of off-gases from monitoring wells was conducted throughout the injection process. Due to the violent nature of this reaction, it was not possible to collect water samples from the monitoring wells during injection. Monitoring wells were sampled daily before the injection process began. Post-test characterization encompassed post-test drilling to verify soil concentrations of TCE and PCE in the treatment zone and sampling and analysis of monitoring wells for a several month period after the injection process had been completed. Sampling of monitoring wells continued until TCE and PCE concentrations stopped increasing, a period of approximately 3 months. Post-test drilling involved 3 soil borings located on a transect running through the test area and within 3 feet of the center of the test zone, with one boring being approximately 10 feet outside the outermost monitoring well. Specific details of the test are addressed below.

In designing this demonstration, decisions had to be made concerning location of the demonstration site, volume of DNAPL to be treated, volume of peroxide and catalyst to be injected, and verification of destruction of DNAPL. Two potential locations for the demonstration were selected based on previous data indicating a high probability of finding DNAPL. Upon drilling both locations, one area was found to contain no indication of DNAPL, while the second area showed soil concentrations of 10 to 150 $\mu\text{g/g}$ of PCE. Highest concentrations were found in a zone at approximately 140 feet below surface, at location A (Figure 3.1).

Five foot screens were used for all installed wells (both monitoring and injector) with the screen zone set from 138 ft to 143 ft below surface. A circular pattern was chosen for the system layout with an injector in the center, ringed by 3 injectors with 3 monitoring wells in a third outer ring. Injectors were set on 17 foot centers with monitoring wells on 27 foot centers. Three vadose zone piezometers were also installed within the treatment area. Figure 5.1 shows a schematic of the system layout. Upon completing pre-test drilling, it was determined that approximately 600 pounds of DNAPL was located within the treatment zone (see Appendix A for equation). The treatment zone was defined as being from the water table to the top of the Green Clay, a zone approximately 30 feet in depth. Testing of the Geo-Cleanse® process occurred over a 6 day period. Injection was conducted in batch mode with one batch injected per day. The injectate was composed of a catalyst of 100 ppm ferrous sulfate which was pH adjusted with concentrated sulfuric acid and the hydrogen peroxide. Three days after the last injection, post-test drilling was initiated to verify destruction of DNAPL. In addition, post-test sampling of monitoring wells was initiated on a weekly basis.

6.0 ANALYSIS AND EVALUATION OF PRE-TEST CHARACTERIZATION SAMPLES

Samples for these tests were analyzed by headspace analysis using a gas chromatograph (GC) with a flame ionization detector (FID) and electron capture detector (ECD) for TCE and PCE. Duplicates were collected for all samples with triplicates collected of samples used in selecting the treatment zone. These triplicate samples were analyzed immediately upon collection by a gas chromatograph with mass-spectrometer (GC-MS) with direct injection of the sample. This allowed for rapid turn around of the sample results leading to rapid decisionmaking on screen zone depth; thus, minimizing down time during the well installation process. (The original and duplicates were analyzed as per standard protocol.) Standards were prepared and run with each batch of samples analyzed. Standard curves were generated and concentrations determined for each analyzed sample. This methodology was followed for all samples analyzed for TCE and PCE throughout the demonstration (treatment test, and post-test).

All pre-test data is provided in Appendix A. Based on analysis of samples from MOX-5 and MOX-6 (first borings at locations A and B, respectively), location A was selected for the demonstration. These two holes were drilled to depths of approximately 155 ft bgs with samples collected continuously from surface to total depth. Sampling to 155 ft ensured sampling to the top of the Green Clay. Sampling intervals were every 10 feet at the surface and decreased to every foot for the bottom 30 feet of each hole (depth from water table to total depth). Small sampling intervals near the bottom of the holes enabled identification of discrete DNAPL zones to the extent possible (remember that DNAPL exists as ganglia below the water table). Data from MOX-5, at location A, showed the presence of TCE and PCE below the water table at a depth of approximately 140 feet bgs. TCE and PCE were present in MOX-6, location B, in the vadose zone only (approximately 90 feet bgs). For this demonstration, the selected site must have DNAPL below the water table. Thus, location A, which is located approximately 50 yards to the west of the closed M-Area Basin, was selected.

Using the data from MOX-5, the well screen depths were selected. MOX-4 and MOX-8 which were drilled to 155 and 165 ft bgs total depth, respectively, confirmed the findings of MOX-5. The remaining 4 wells for the demonstration were drilled to a total depth of 144 ft bgs. All seven wells at the demonstration site were screened from 138 ft to 143 ft bgs. These holes were sampled from above the water table (approximately 125 ft bgs) to total depth at intervals every 2 feet for the first 5 to 10 feet then at intervals of 1 foot until reaching total depth.

The majority of the DNAPL at location A was detected in a zone from 138 ft bgs to 144 ft bgs, collected on a clay stringer approximately 10 ft above the Green Clay. Small quantities of PCE and TCE were detected below the Green Clay, a leaky aquitard that separates the water table zone (M Area Aquifer) from a semiconfined zone (Lost Lake Aquifer). Volume of DNAPL in the target treatment zone was calculated using all pre-test characterization data at Location A (see Appendix A for calculation). The treatment zone extended vertically from the water table to the top of the Green Clay (approximately 30 ft thick) and

laterally a circular area of radius 27 feet from the center injector. Volumes of DNAPL present were calculated over 1 foot increments by averaging the soil core data within each increment. The volumes were added and a total volume of 593 pounds of DNAPL was calculated.

Pre-test data, collected from MOX-5, MOX-7 and MOX-8, included average PCE and TCE water concentrations of 119.49 mg/L and 21.3 mg/L, respectively. Average baseline pH, temperature and chloride readings were 5.71 pH units, 19.2° C and 3.61 mg/L, respectively.

7.0 ANALYSIS AND EVALUATION OF TREATMENT TEST SAMPLES

During the six day treatment test, water samples were collected from the monitoring wells (MOX-5, 7 and 8) and analyzed for PCE, TCE, pH, temperature, and chloride ion. Water samples were collected in the morning before the batch injections. Water sampling was limited due to poor pump performance caused by gases entrained in the groundwater during and immediately following injection. Bubbling was heard emanating from the monitoring wells during operation, corroborating the hypothesis that entrained gases were the cause of the poor performance of the pumps. Average contaminant concentrations in the treatment area groundwater were 119.49 mg/L PCE and 21.31 mg/L TCE before treatment and were reduced to 0.65 mg/L PCE and 0.07 mg/L TCE at completion of treatment. Average pH before treatment was 5.71 and 2.44 at completion of treatment. Reduction in pH was due to addition of acid to reduce pH for optimal oxidation and, to some extent, reduction of pH due to increase in CO₂ from the destruction process. Average baseline groundwater temperature in the treatment zone was 19.2° C and was raised to a maximum of 34.7° C by the oxidation process. Average baseline chloride concentration was 3.61 mg/L and reached a maximum of 24.33 mg/L at the completion of the treatment process. The increase in chloride concentration verifies breakdown (oxidation) of PCE and TCE which was contacted by the peroxide. Hydrogen peroxide (H₂O₂) concentrations in the monitoring wells ranged from approximately 2 to 5 ppm. Data from the in situ oxidation treatment period is shown in Figure 7.1. A time history of the hydrogen peroxide batch injections, PCE and TCE, and chloride concentrations is illustrated in these charts.

Three vadose zone wells, screened approximately 10 ft above the water table, were monitored for increases in CO₂ and TCE and PCE volatilizing from the groundwater. Increases in concentrations of these three parameters were not observed. This may be accounted for by the distance of the piezometers above the treatment zone and interbedded sand and clay between the piezometers and treatment zone acting as barriers to upward migration.

Gaseous headspace from the monitoring wells was monitored for CO₂, PCE, and TCE during the injection process. Gases were escaping from water in the monitoring wells during injection due to the violent oxidation process. Carbon dioxide levels from gases escaping from the monitoring wells rose to over 3,500 ppmv (ambient CO₂ levels are approximately 300-400 ppmv). Elevated CO₂ levels verify DNAPL oxidation in the subsurface to H₂O, CO₂, and Cl⁻ based on stoichiometry presented in equation 3 (Section 4.1). PCE and TCE were evident in the gas and can be attributed to sparging of water in the wells. PCE and TCE gas concentrations from the headspace of the monitoring wells during the oxidation process ranged from 0 to 190 ppmv PCE and 0 to 80 ppmv TCE.

8.0 ANALYSIS AND EVALUATION OF POST-TEST CHARACTERIZATION SAMPLES

Three post test soil borings were conducted to obtain sediment samples for VOC analysis to determine effectiveness of the treatment process. A significant decrease in PCE and TCE concentration was observed in post-test sediment samples. Post-test borings were located on a transect running through the test area and within 3 feet of the center of the test zone (MOX-10 and 11), with one boring being approximately 10 feet outside the outermost monitoring well (MOX-9). The outermost boring, MOX-9, was outside the expected treatment zone and was used to verify the DNAPL had not been moved out of the treatment zone. See Figure 5.1.

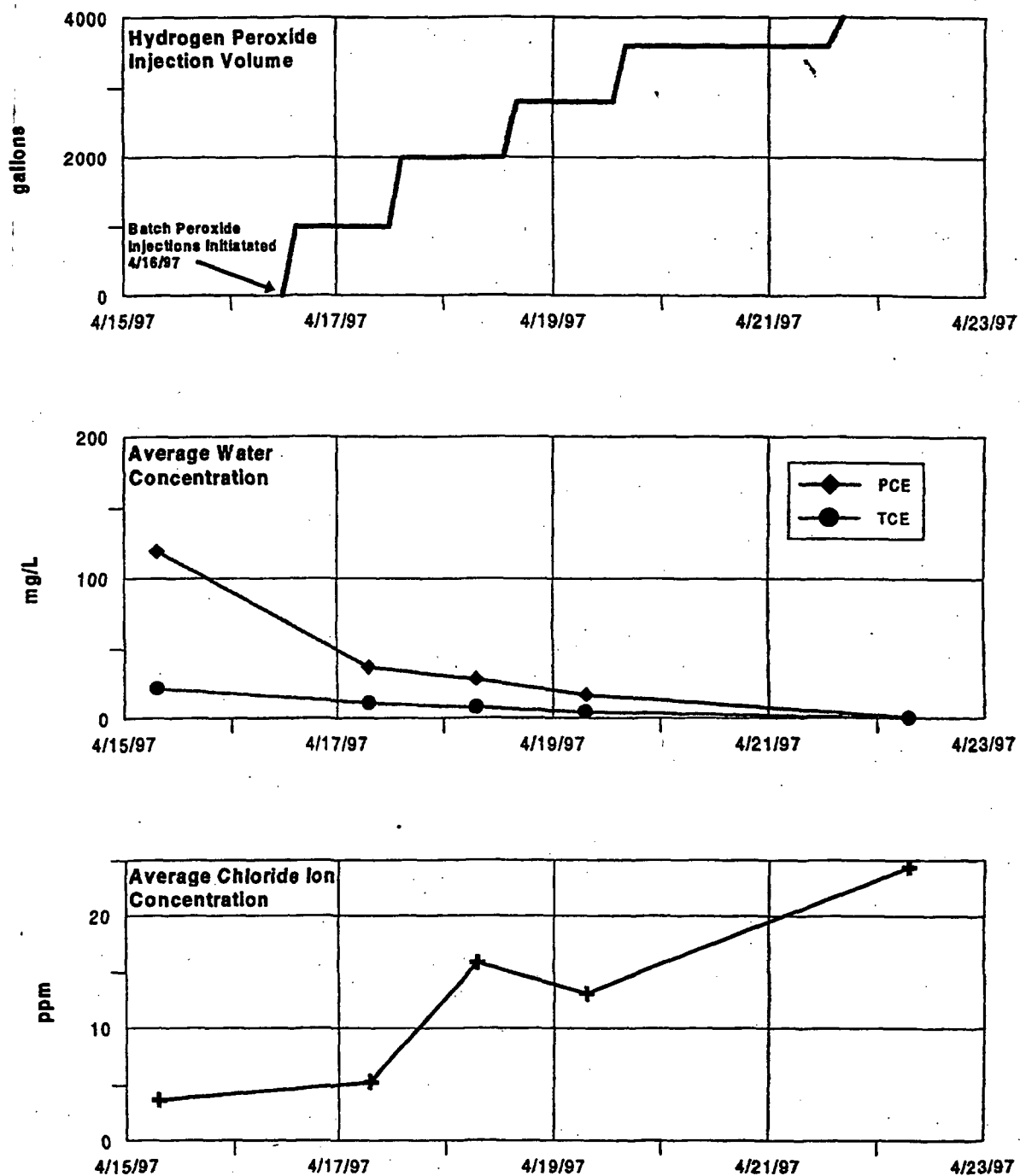


Figure 7.1 - In Situ Oxidation Treatment Period Data

Samples for these tests were analyzed by headspace analysis using a gas chromatograph (GC) with a flame ionization detector (FID) and electron capture detector (ECD) for TCE and PCE, Appendix B. Duplicates were collected for all samples. Standards were prepared and run with each batch of samples analyzed. Standard curves were generated, and concentrations determined for each analyzed sample.

All post-test data is provided in Appendix A. Sediment sampling began at 117 ft bgs at an interval of every foot for the bottom 30 ft of each hole, approximately. MOX-9 was completed to 152 ft, MOX-10 to 153 ft, and MOX-11 to 156 ft bgs. MOX-11 was sampled through the Green Clay confining zone to determine if any DNAPL had been pushed through the unit. The Green Clay formation is located at approximately 152 ft bgs. Small sampling intervals near the bottom of the holes enabled identification of DNAPL zones to the extent possible.

A dramatic decrease in VOC sediment concentrations was observed compared to pre-test borings indicating destruction of DNAPL in the treatment zone. These findings will be discussed in Section 9.0.

9.0 EVALUATION OF DEMONSTRATION SUCCESS

Success of the demonstration is based on destruction of DNAPL in the treatment zone. The best measure of destruction success is based on measurement of DNAPL globules in the sediment before and after the treatment process. Destruction was measured by conducting pre- and post-test soil borings and measuring the amount of PCE and TCE in the sediment. A comparison of sediment concentrations for PCE and TCE from boring MOX-1 (pre-test) and MOX-11 (post-test) is presented in Figure 9.1 (Appendix A contains the profiles for the remaining borings and wells). A significant decrease in sediment concentrations is evident. The estimated pre-test mass of DNAPL in the treatment zone was 593 lbs, and the estimated post-test mass of DNAPL was 36 lbs. This results in a 94% destruction rate estimated for the treatment zone. The treatment zone is defined as the vertical distance between the water table (124 ft bgs) and the Green Clay (152 ft bgs) and a 27 ft radius around the center injector. The estimated mass of DNAPL in the treatment zone before and after the test is presented in Table 9.1. Mass of contaminants was estimated by averaging sediment concentrations at one foot depth intervals and assuming a treatment zone of 64,000 ft³. Estimation of the PCE and TCE destruction using chloride ion concentration changes during the test will be planned.

Table 9.1 Calculated Pre- and Post-Test DNAPL Mass and Destruction for the In Situ Oxidation Demonstration

| Location | Pre-Test, lbs | | | Post-Test, lbs | | | Destruction | | |
|------------------|---------------|-------|--------|----------------|------|-------|-------------|-------|-------|
| | PCE | TCE | Total | PCE | TCE | Total | PCE | TCE | Total |
| Above Green Clay | 528.53 | 64.56 | 593.09 | 28.24 | 7.95 | 36.19 | 94.7% | 87.7% | 93.9% |
| Below Green Clay | 36.23 | 13.07 | 49.30 | 26.96 | 9.98 | 36.94 | 25.6% | 23.6% | 24.5% |

PCE and TCE water concentrations in the monitoring wells were judged to not provide a representative measure of destruction. The basis for this being 1) groundwater will come into equilibrium with contaminants not destroyed; and 2) the zone is subject to migration of contaminated water from up gradient. A graphical depiction of the total pounds of DNAPL by one foot intervals in the treatment zone is shown in Figure 9.2. The location of the injection zone (5 ft injector screen lengths) and the location of the Green Clay is shown. The Green Clay acts as a semi-confining unit, which is indicated in part by the higher DNAPL mass and destruction efficiency above the Green Clay than below it. The semi-confining nature of the Green Clay is also supported by hydrologic and geologic data. A total destruction of all DNAPL was not achieved and can be attributed to the process not contacting all DNAPL globules in the fine grained sediments. Injected hydrogen peroxide will take the path of least resistance through areas of higher permeability, which in this case will be through sandy regions of the treatment zone.

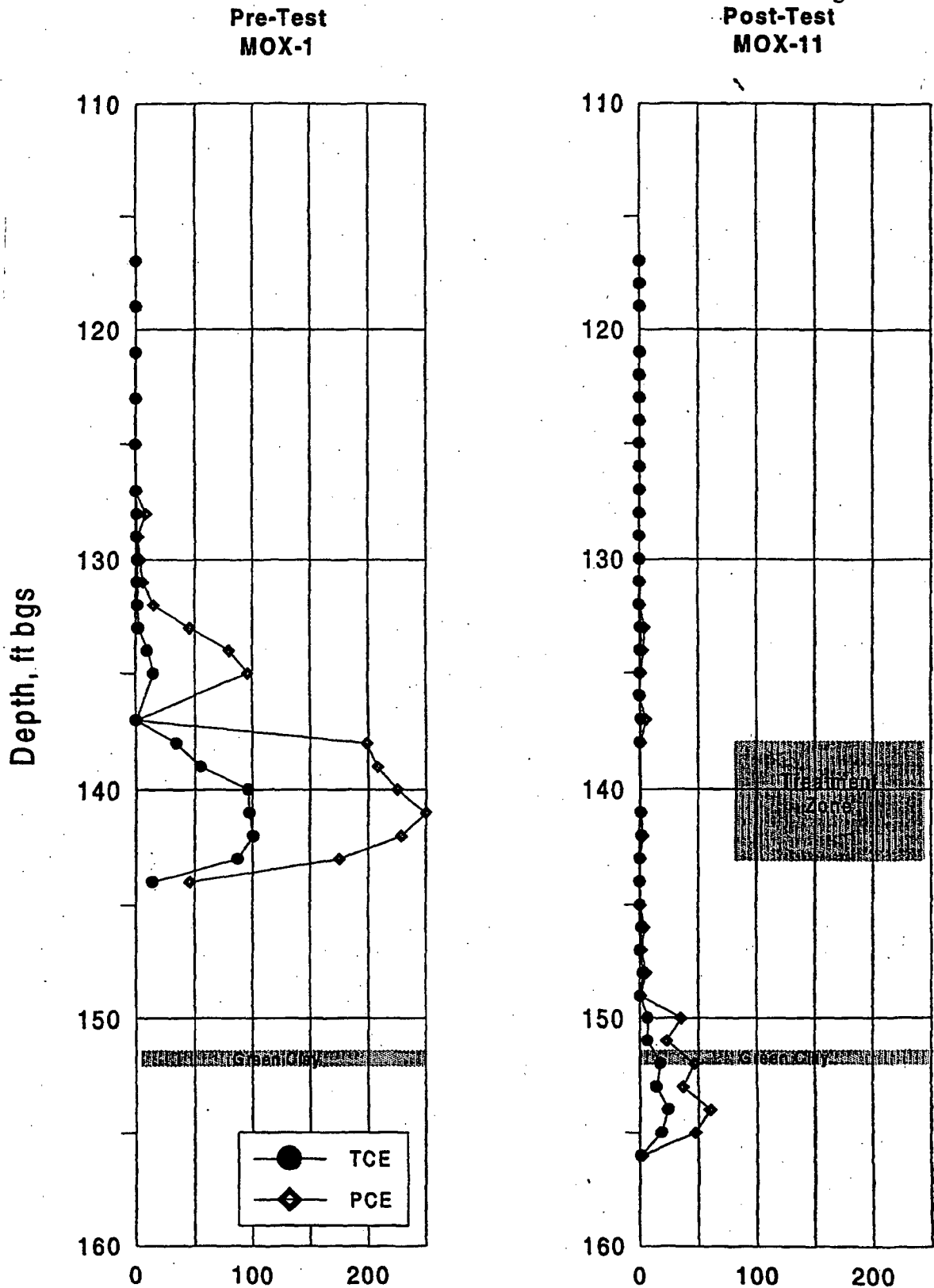


Figure 9.1 - Pre and Post-Test Sediment Concentrations

CVOCs, lbs per 1 Foot Reaction Zone Interval

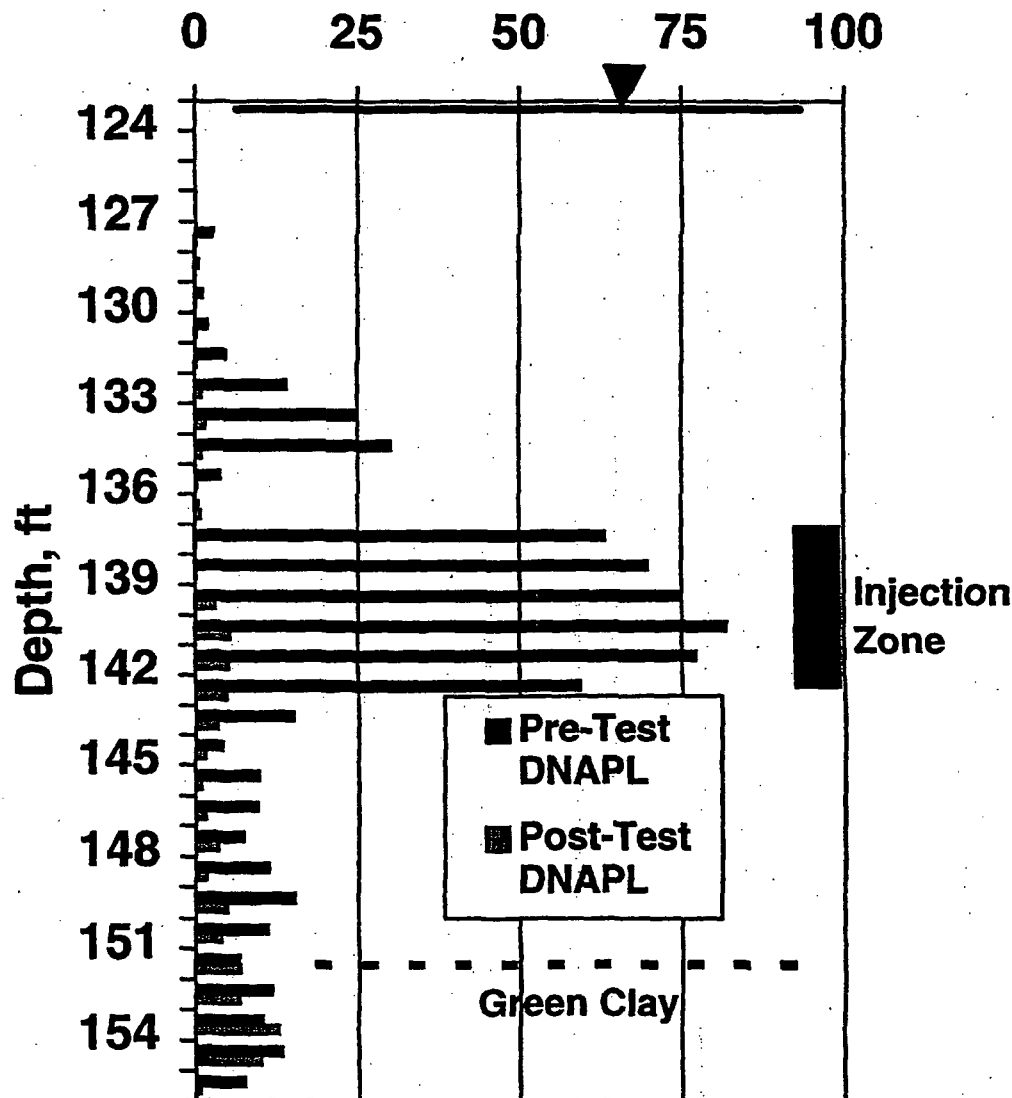


Figure 9.2 - Pre and Post Test DNAPL Mass for the In Situ Oxidation Demonstration

Groundwater concentrations began rebounding in the monitoring wells after treatment was completed. Rebound in the treatment zone can be attributed to groundwater coming into equilibrium with small DNAPL globules not treated. Some of the small DNAPL globules in the fine grained sediments were probably not contacted by the hydrogen peroxide and were therefore not oxidized. Concentration data from the three monitoring wells is shown in Figure 9.3. Groundwater concentration in MOX-8 is rebounding faster than MOX-5 and 7 and can be attributed to direction of groundwater flow in the area. Groundwater is flowing approximately across the site from MOX-8 to MOX-5 (see Figure 5.1) at an estimated velocity of a few inches per day. DNAPL is expected to be in the subsurface between the treatment site and the M-Area Settling Basin, source of DNAPL contamination. Chloride ion

concentration increased significantly during the injection process and then leveled off at a higher concentration than the baseline. Chloride ion is a product of the oxidation of PCE and TCE. Post-treatment chloride concentrations in monitoring well MOX-5 are slightly elevated compared to MOX-7 and MOX-8 and can be attributed to groundwater flow from the treatment zone towards MOX-5. A time history of the chloride concentration is shown in Figure 9.4.

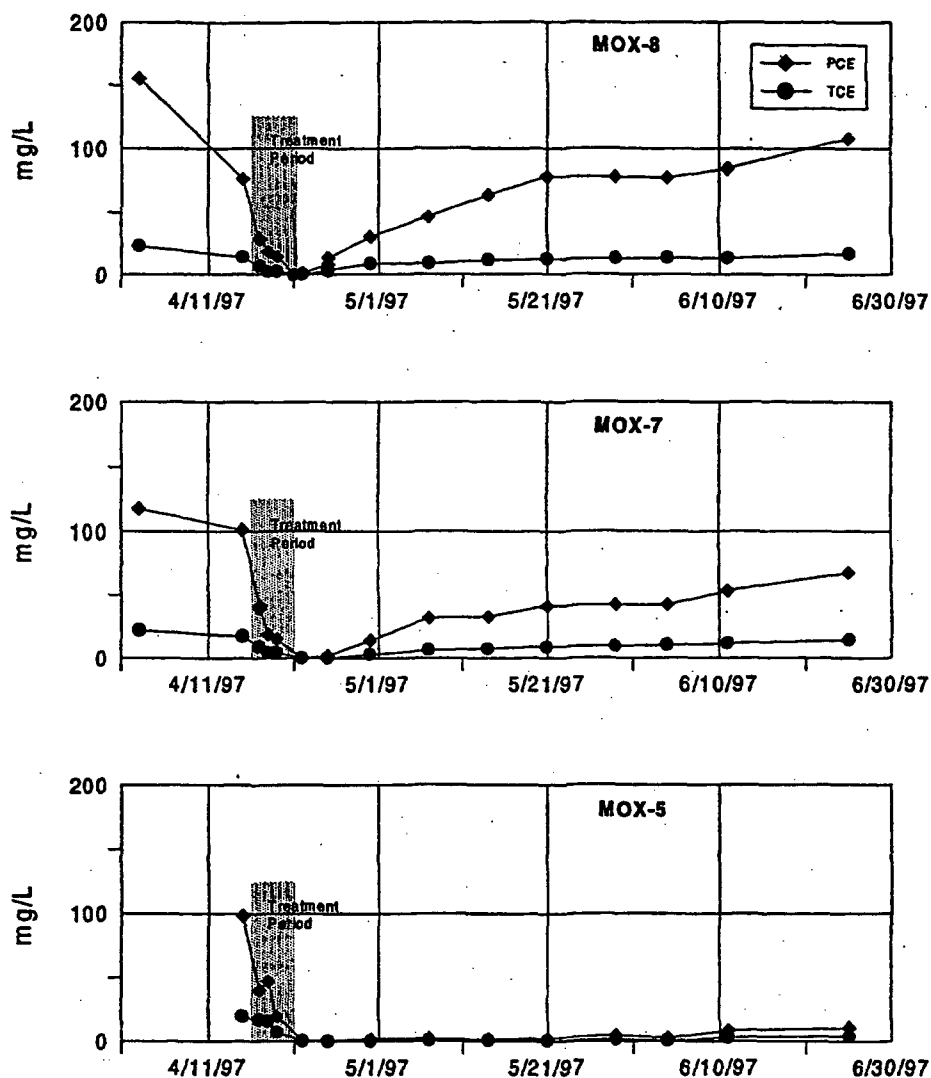


Figure 9.3 - Monitoring Well Concentrations Showing Rebound of Contaminant Concentration for In Situ Oxidation Demonstration

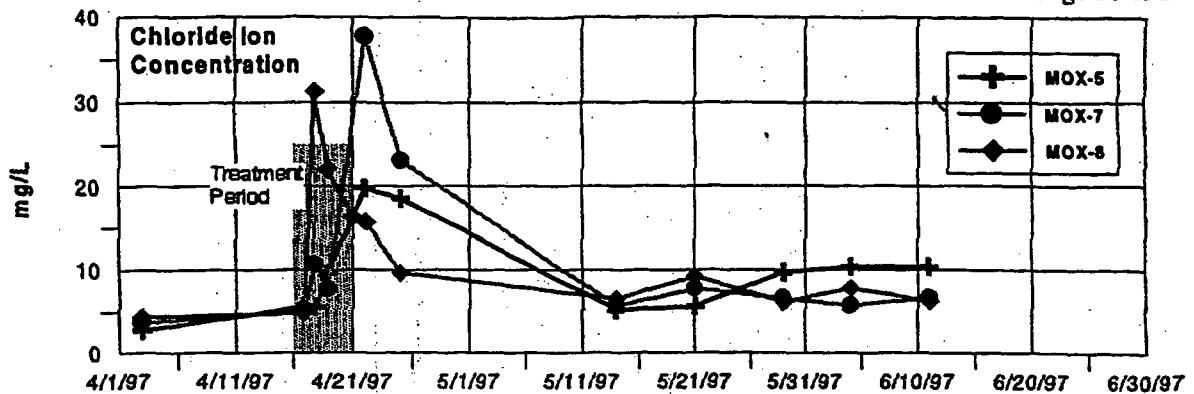


Figure 9.4 - Chloride Ion Concentration for In Situ Oxidation Demonstration

10.0 COST EVALUATION OF DEMONSTRATION

This cost evaluation will examine the costs of this demonstration from two perspectives. First, the overall cost of the demonstration will be discussed in relationship to the influence of each component of the demonstration (i.e. drilling costs, chemicals, documentation). Second, cost on a per pound of DNAPL removed basis will be determined and compared to the cost per pound of DNAPL removed for the baseline system of pump and treat using air stripping.

10.1 Overall Cost of Demonstration in Relationship to Sensitivity to each Component of Demonstration

Demonstration activities were placed in one of six categories: site preparation, pre-test drilling and characterization, technology test, post-test drilling and characterization, demobilization, and documentation/project management. Table 10.1 presents costs for each of these categories.

Table 10.1 Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Activity Category

| Activity Categories | Cost |
|---|------------------|
| Site Preparation | \$ 60,422 |
| Pre-test drilling and characterization | \$150,738 |
| Technology Test | \$183,539 |
| Post-test drilling and characterization | \$ 49,477 |
| Post-test demobilization | \$ 6,934 |
| Documentation and Project Management | \$ 60,005 |
| TOTAL | \$511,115 |

The majority of the costs are related to the technology test and the pre-test drilling and characterization. Table 10.2 provides a list of tasks for each activity category. In order to identify which tasks are sensitive to variations in site conditions, an understanding of each task is needed. Below the tasks are discussed in association with their respective activity categories.

Table 10.2 Costs for In Situ Oxidation Using Fenton's Chemistry Demonstration Identified by Task

| CATEGORY/TASK | COST | CATEGORY/TASK | COST |
|--|-----------|--|----------|
| Site Preparation and Operation Activities | | Post-test Drilling and Characterization | |
| Construct Secondary Containments | \$10,425 | Drilling Subcontract | \$22,000 |
| Generator Rental | \$6,456 | Oversight and Sampling | \$20,888 |
| Electrical Hookup | \$12,411 | Analysis | \$6,589 |
| Signs | \$5,098 | Post-test Demobilization | |
| Tanks Setup | \$11,081 | Disconnect Electrical Hookups | \$2,677 |
| Water Supply | \$4,320 | Tear down secondary containments | \$2,764 |
| Clearing/Grubbing | \$10,631 | Remove generators | \$1,493 |
| Pre-test Drilling and Characterization | | Documentation and Project Management | |
| Drilling Subcontract | \$85,000 | Documents | \$36,003 |
| Oversight and Sampling (provided by WSRC) | \$44,070 | Project Management (provided by WSRC) | \$24,002 |
| Analysis | \$19,229 | | |
| Sampling Supplies | \$2,439 | | |
| Technology Test | | | |
| Oversight | \$14,627 | | |
| Peroxide | \$20,412 | | |
| Operation | \$148,500 | | |

- Tasks associated with site preparation are essentially constant. Implementation of this technology does not require permanent infrastructure such as a permanent power source, permanent water and chemical tanks, etc. Temporary power is required for operation of the system. This is much less expensive for the short duration of operation, typically less than 1 month and in many instances 1 to 2 weeks. Also required is a constant supply of water for process, as well as emergency, purposes. For remote sites where a distribution line with potable water is not available tanks for water storage are appropriate. For this demonstration, tanks were obtained from the material excess yard located at SRS; thus, not incurring additional costs to the project. Use of existing tanks is acceptable, as long as they have been cleaned (rinsing the inside of the tanks and draining several times with potable water should be sufficient). During the demonstration, approximately 1000 gallons of water per day was used for a 6 day period.
- Pre-test drilling and characterization costs will vary according to site characteristics. In the A/M-Area, the core holes were drilled to total depths ranging from 144 ft bgs to 155 ft bgs. All pre-test holes were completed as wells. The cost per well was approximately \$10,500 or \$70/ft. These costs include drilling, setting the well, all well materials, well development, and well finishing (posts and pads). Thus, depth to contamination will have a large effect on the cost of the drilling activities

Sampling and analyses costs will vary linearly with depth to contamination. Most sampling activities for this demonstration were concentrated below the water table. This will be required regardless of

overall depth. Because of the nature of DNAPL (thin ganglia below the water table), it is necessary to sample at small intervals to identify discrete DNAPL zone(s). Preliminary characterization, which would lead to choosing this technology, should help to identify the approximate zone in which DNAPL would be present. However, discrete sampling will be required to "pinpoint" the location for setting screen zones of injectors and for providing an accurate estimate of the quantity of DNAPL to be destroyed.

- Costs for the technology treatment (\$148,500) are the largest component of the treatment operation. The majority of these costs are labor and use of equipment. Thus, they are based on duration of the work. Peroxide costs were \$20,412 for 42,000 pounds of peroxide, use of an ISO tank capable of holding 45,000 pounds of peroxide, and a dosing unit for transfer from the tank to the Geo-Cleanse® process equipment. Thus, peroxide costs are approximately \$0.50/pound. For this demonstration, the treatment zone was a circular area with a 27 foot diameter and a depth of approximately 30 feet for a total volume of 68,702 ft³. The controlling factor is the amount of contaminant present at the site. At the demonstration site, the estimated volume of DNAPL based on pre-test characterization is approximately 600 pounds. The third component of the technology costs is oversight. These costs are dependent on duration of treatment.
- Post-test drilling and characterization costs, as with pre-test characterization costs will be dependent on depth. For this demonstration three post-test holes were drilled to a total depth of 155 ft. and samples collected from the water table to total depth. As stated above, sampling and analysis costs should vary linearly with depth.
- Post-test demobilization costs are a small fraction of the entire project costs. They include removal of water tanks, disconnecting the power supply, removal of the generator, and disassembly of secondary containments.
- Documentation and project management costs are approximately 12 percent of the demonstration, with 5 percent of total costs going to project management activities and 7 percent of total costs attributed to documentation activities. Documentation includes a test plan, all regulatory documents for drilling and underground injection, scopes of work for drilling services and other materials, and a test report documenting the results of the demonstration.

After reviewing each specific activity, costs, and factors affecting costs, two items stand out. These are costs of drilling activities and cost of peroxide. Drilling costs are approximately \$70/ft. This includes drilling charges, well installation, well materials, and well completion charges. Peroxide costs \$0.50/pound. Peroxide usage is based on 42 pounds of peroxide per pound of DNAPL. Thus, the cost of peroxide per pound of DNAPL present is \$21. For a small site (i.e. 2,000 pounds of DNAPL), peroxide costs will not be a significant portion of the entire remediation costs, less than 10%. For a large site (i.e. 15,000 pounds of DNAPL), the peroxide costs can be a significant portion of the total remediation costs, 20% and greater. Thus, depth to contamination and amount of DNAPL present will be driving factors in determining costs for use of this technology.

10.2 Unit Cost of In Situ Oxidation Technology

In an effort to determine the cost effectiveness of this technology, a unit cost based on a pound of DNAPL treated or destroyed was determined and compared to the unit cost of the baseline technology. For A/M-Area, the baseline technology is pump and treat using airstripping. The baseline cost is \$87/pound DNAPL treated. Appendix C provides the basis for the baseline cost for the pump and treat system. DNAPL in A/M-Area is detected above the Green Clay, located at an approximate depth of 155 ft below surface. For that depth, approximately 9,500 pounds of DNAPL must be present to have a unit cost for in situ oxidation equal to the baseline cost for pump and treat. For DNAPL contamination at a depth of approximately 60 ft below surface, 6,500 pounds of DNAPL will yield the equivalent unit cost.

In reviewing costs of each component of this demonstration, items which are essentially fixed costs were identified along with those which are dependent on site conditions. Mobilization, site setup, demobilization, and document preparation were assumed to be fixed costs. Materials and equipment mobilized for injection are independent of site size. Size of the site will effect duration of operation rather than sizing of equipment. Document preparation requires well construction approval forms and an Underground Injection Control Permit. A test plan is also a valuable document to submit to the regulator agencies to provide information on why and how the work will be completed. For CERCLA sites, a Proposed Plan and Record of Decision would be required, but costs for these documents should be fixed.

Site conditions affecting costs are pounds of DNAPL present and depth to contamination. Depth to contamination in this context refers to the major volume of the plume and not the shallowest depth at which measurable concentrations are detected. Site conditions influence days of operating the treatment system, days for drilling, days for oversight, and number of analyses. As depth to contamination increases, days of drilling and oversight and number of analyses will increase. As DNAPL contamination increases, days of operating the treatment system will increase.

In order to calculate a unit cost of treatment per pound of DNAPL destroyed, an equation was created based on activities required to complete remediation. The general equation is listed below with the detailed equation provided in Appendix D. Because this treatment technique is of a short duration, the operations equipment is portable. Thus no permanent structures nor longterm maintenance activities are included.

$$\text{Unit Cost} = (\text{Mobilization/Setup} + \text{Pre-test Characterization} + \text{Treatment System} \\ \text{Operation} + \text{Peroxide} + \text{Demobilization} + \text{Document Preparation} + \\ \text{Post-test Characterization} + \text{Project Management})/\text{Pound of DNAPL}$$

Table 10.3 presents data used to determine the break even unit cost with the pump and treat unit cost. This data is represented by Figures 10.1 and 10.2. These figures represent the same data. Figure 10.1 provides a complete look at the data with Figure 10.2 showing the data near the break even point. The break even point is dependent on depth to contamination, as seen in Figures 10.1 and 10.2. This occurs at volumes ranging from 6,500 pounds to 9,500 pounds of DNAPL as depth to contamination increases from 60 ft to 155 ft, as seen in Figure 10.2. Unit cost of in situ oxidation at sites with small volumes of DNAPL, less than 4000 pounds, is greater than \$100/pound of DNAPL, as seen in Figure 10.1. Unit costs escalate to greater than \$700/pound of DNAPL for sites with approximately 1000 pounds of DNAPL. The unit cost for pump and treat using airstripping is currently \$87/pound of DNAPL (note that this is related to groundwater concentration, and the unit cost will increase over time as the concentrations decrease).

Unit costs for remediation technologies are often compared on a \$/ft³ of soil treated. The \$/ft³ of soil treated was calculated at the \$/lb DNAPL breakeven point between in situ oxidation and pump and treat for the three depths evaluated. The calculation is presented in Appendix D. The unit costs on a \$/ft³ basis are \$8.84/ft³, \$9.95/ft³ and \$13.03/ft³ for depths of 60 ft, 100 ft and 155 ft to DNAPL contamination, respectively.

Table 10.3 Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a Function of Depth to Contamination

| DNAPL (lbs) | UNIT COSTS (\$/lb DNAPL) | | |
|-------------|--------------------------|--------------|--------------|
| | 60 ft depth | 100 ft depth | 155 ft depth |
| 500 | 708 | 816 | 917 |
| 1,000 | 365 | 419 | 469 |
| 2,000 | 194 | 221 | 246 |
| 5,000 | 105 | 116 | 126 |
| 6,000 | 92 | 101 | 109 |
| 6,750 | | 92 | 99 |
| 7,500 | 78 | | 92 |
| 9,000 | 79 | 85 | 90 |
| 10,000 | 73 | 78 | |
| 11,000 | 68 | 73 | 78 |
| 12,000 | 65 | 69 | 73 |

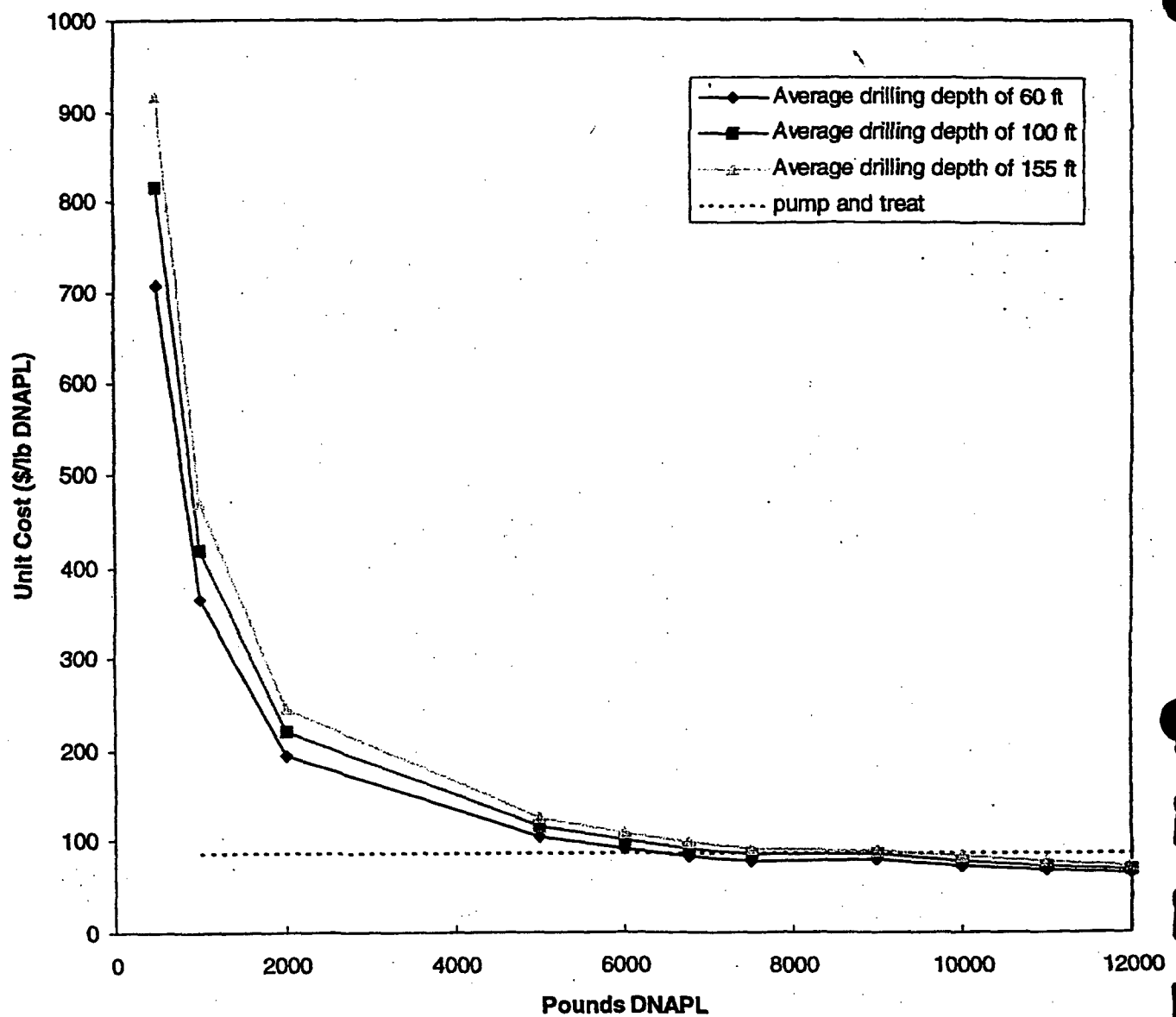


Figure 10.1 Full Scale Representation of Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a function of depth to Contamination

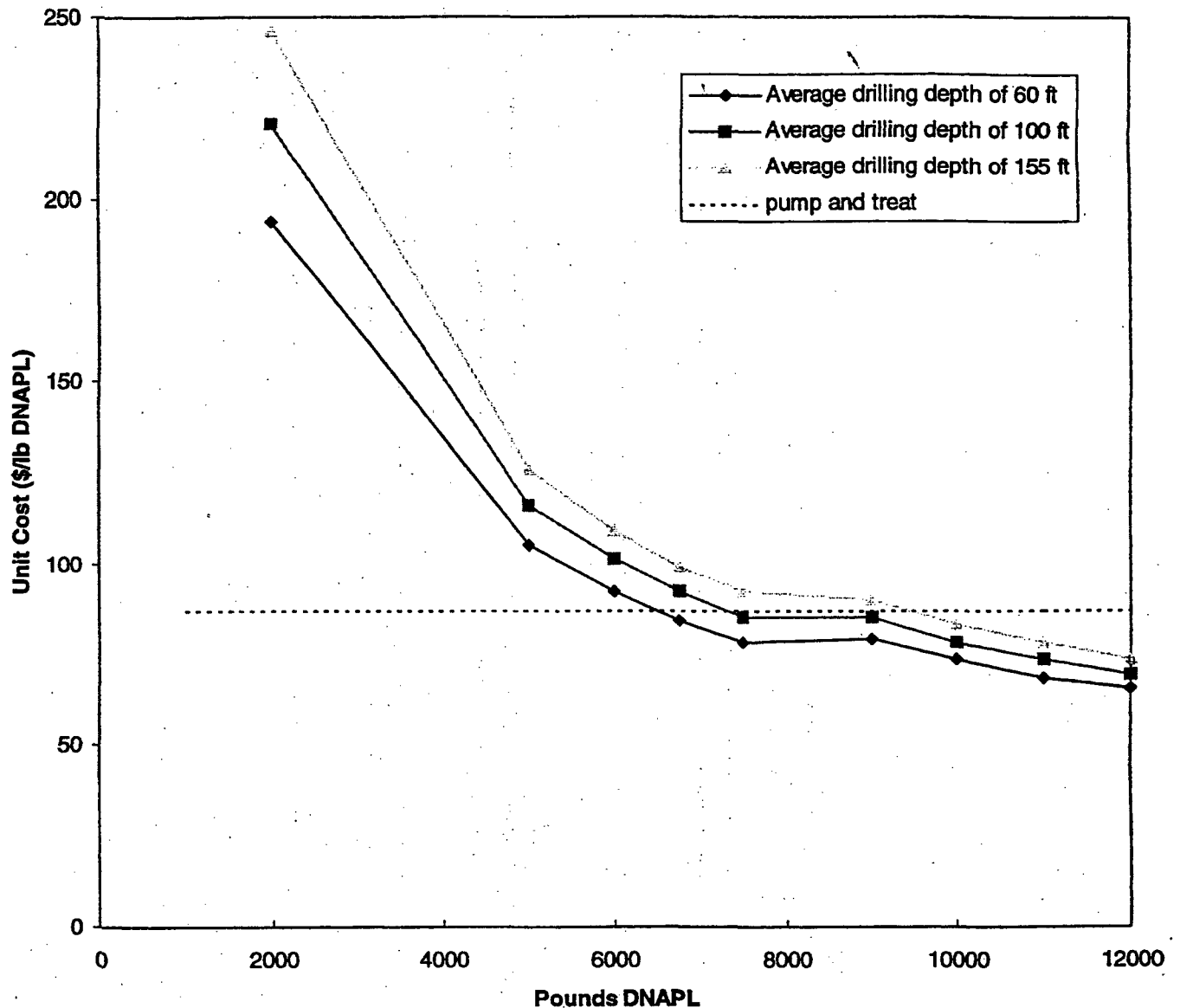


Figure 10.2 Unit Cost/Pound of DNAPL Destroyed for Implementation of In Situ Oxidation for Destruction of DNAPL as a Function of Depth to Contamination

11.0 DISCUSSION OF RESULTS

During this demonstration approximately 600 pounds of DNAPL was destroyed in a six day operating period, leaving a residual of 40 pounds of DNAPL in the target zone. This is a 94% destruction efficiency. In situ oxidation using Fenton's chemistry was the process evaluated during this demonstration. The cost of the demonstration was approximately \$500,000. On a unit cost basis, this technology becomes cost competitive with pump and treat using airstripping (\$87/pound DNAPL) for a DNAPL pool of approximately 9,500 pounds at a depth of 155 ft bgs. Depth is a major contributor to the

overall costs when this technology is employed. For a DNAPL pool of volume V, as depth to the DNAPL pool increases the costs for remediation will increase. Thus, both the size of the DNAPL pool and the depth to the DNAPL pool must be considered in determining when this technology becomes cost competitive with pump and treat using airstripping.

Other factors contributing to the decision to use this technology include duration of treatment, volume of DNAPL, and end products of treatment. Ninety-four percent of a 600 pound plume were destroyed in a six day period during this demonstration. Injection was in a circular area with radius 27 feet and operation was approximately 6 hours per day using 4 injectors. Duration of operation is not a linear function of volume of DNAPL. Factors effecting the duration of the treatment would include: other compounds which may be oxidized under similar conditions, geochemical makeup of treatment zone, and tightness of treatment zone (i.e., access to DNAPL). The site of the demonstration was not completely saturated with DNAPL. In preparing the Test Plan, an estimated volume at this site (assuming a two foot zone had been fully saturated) was 50,000 pounds of DNAPL. The vendor, Geo-Cleanse International, Inc. estimated a 10 day duration for treatment of the demonstration site with a 50,000 pound volume of DNAPL. The evaluation of unit costs, identified that depth to DNAPL is inversely related to volume of DNAPL in the treatment zone. However, at least 6,000 pounds of DNAPL is required at a site with the DNAPL pool at a depth of 60 feet to make this treatment cost competitive with pump and treat systems. With this in mind, an appropriate site for using in situ oxidation would be the DNAPL source.

The end products of in situ oxidation are very appealing. No waste is generated from the treatment process, and no material is brought to the surface. The end products of this process are carbon dioxide, water, and chloride ions. All of these compounds are considered innocuous materials.

Additional questions were raised as the demonstration progressed and data was collected. Many of the questions concerned the geochemistry and microbiology in the treatment zone. Because in situ oxidation is a very robust chemical reaction, a reasonable assumption is that most microbial activity was destroyed during the reaction. The type of microbial activity that will return to the area and to what extent is not known. We also saw the pH drop dramatically from an average pH of 5.7 before treatment to 2.4 at completion of treatment. Post-test treatment has shown a very slow rebound of the groundwater pH. Three months after completion of the test, the groundwater pH remains at approximately 3.5. It is not known as to whether this is due to changes in the geochemistry. Work is proposed for FY98 to conduct additional post-test studies to answer these and other questions.

REFERENCES

Westinghouse Savannah River Company. *Assessing DNAPL Contamination, A/M-Area, Savannah River Site: Phase I Results (U)*, WSRC-RP-92-1302, December 1992. Prepared for the U.S. Department of Energy under Contract No. DE-AC09-89SR18035.

Westinghouse Savannah River Company. *Test Plan for Geo-Cleanse Demonstration (In Situ Destruction of Dense Non-Aqueous Phase Liquid (DNAPL))*, WSRC-RP-96-441, September 1996. Prepared for the U. S. Department of Energy under Contract No. DE-AC09-89SR18035.

APPENDIX A

RAW DATA AND SOIL CONCENTRATION DEPTH PROFILES FOR IN SITU OXIDATION
DEMONSTRATION

Well and Boring Coordinates with Ground Surface Elevation

| ID | Description | SRS Site Coordinates | | Elevation ft msl |
|--------|------------------|----------------------|-----------|---------------------|
| | | Northing | Easting | |
| MOX-1 | Injector | 102412.627 | 48268.202 | 353.649 |
| MOX-2 | Injector | 102414.600 | 48237.618 | 352.960 |
| MOX-3 | Injector | 102388.561 | 48251.611 | 353.412 |
| MOX-4 | Injector | 102406.310 | 48252.180 | 353.109 |
| MOX-5 | Monitoring Well | 102419.057 | 48227.797 | 352.979 |
| MOX-6 | Monitoring Well | 102212.283 | 48830.626 | 355.520 |
| MOX-7 | Monitoring Well | 102417.415 | 48277.433 | 354.392 |
| MOX-8 | Monitoring Well | 102379.281 | 48250.906 | 353.784 |
| MOX-10 | Post Test Boring | 102415.125 | 48248.511 | 352.917 |
| MOX-11 | Post Test Boring | 102404.620 | 48271.597 | 353.794 |
| MOX-9 | Post Test Boring | 102433.337 | 48212.416 | 353.557 |
| MOX-1V | Vadose Well | 102378.881 | 48265.261 | 354.485 |
| MOX-2V | Vadose Well | 102412.528 | 48215.546 | 353.114 |
| MOX-3V | Vadose Well | 102428.040 | 48272.590 | 353.684 |
| MOX-4V | Vadose Well | 102400.446 | 48263.701 | 353.753 |

Concentration Data for MOX-1 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|----------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0100 | 117 | 236.6 | 4.17 | 0 | 0 | 0.0008 | 0.0009 |
| MOX0100 | 117 | 236.6 | 3.78 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0101 | 119 | 234.6 | 3.97 | | 0 | 0.0000 | 0.0005 |
| MOX0101 | 119 | 234.6 | 4.59 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0102 | 121 | 232.6 | 3.68 | 44 | 0 | 0.0905 | 0.0004 |
| MOX0102 | 121 | 232.6 | 3.48 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0103 | 123 | 230.6 | 3.75 | | 0 | 0.0000 | 0.0006 |
| MOX0103 | 123 | 230.6 | 3.99 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0104 | 125 | 228.6 | 3.61 | 2 | 2 | 0.0090 | 0.0085 |
| MOX0104 | 125 | 228.6 | 3.49 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0105 | 127 | 226.6 | 3.97 | 5 | 3 | 0.0172 | 0.0100 |
| MOX0105 | 127 | 226.6 | 3.58 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0106 | 128 | 225.6 | 4.41 | 309 | 2461 | 1.0522 | 8.3717 |
| MOX0106 | 128 | 225.6 | 4.61 | 37 | 158 | 0.1111 | 0.4805 |
| MOX0107 | 129 | 224.6 | 3.78 | 168 | 364 | 0.6649 | 1.4436 |
| MOX0107 | 129 | 224.6 | 3.88 | 166 | 620 | 0.5992 | 2.2372 |
| MOX0108 | 130 | 223.6 | 3.55 | 263 | 747 | 1.1103 | 3.1577 |
| MOX0108 | 130 | 223.6 | 3.82 | 108 | 412 | 0.3959 | 1.5122 |
| MOX0109 | 131 | 222.6 | 3.94 | 350 | 1484 | 1.2458 | 5.2761 |
| MOX0110 | 132 | 221.6 | 3.90 | 344 | 3863 | 1.3231 | 14.8591 |
| MOX0110 | 132 | 221.6 | 3.91 | 179 | 703 | 0.6423 | 2.5177 |
| MOX0111 | 133 | 220.6 | 3.43 | 426 | 10444 | 1.8622 | 45.6716 |
| MOX0111 | 133 | 220.6 | 3.87 | 583 | 3285 | 2.1100 | 11.8901 |
| MOX0112 | 134 | 219.6 | 4.08 | 2562 | 21711 | 9.4181 | 79.8210 |
| MOX0112 | 134 | 219.6 | 3.68 | 599 | 3547 | 2.2800 | 13.5028 |
| MOX0113 | 135 | 218.6 | 4.56 | 4546 | 29109 | 14.9531 | 95.7525 |
| MOX0113 | 135 | 218.6 | 4.49 | 819 | 4768 | 2.5544 | 14.8737 |
| MOX0114 | 137 | 216.6 | 4.18 | 24 | 86 | 0.0861 | 0.3077 |
| MOX0114 | 137 | 216.6 | 3.27 | 0 | 17 | 0.0000 | 0.0709 |
| MOX0115 | 138 | 215.6 | 4.31 | 9863 | 57121 | 34.3270 | 198.7972 |
| MOX0115 | 138 | 215.6 | 3.66 | 1398 | 9029 | 5.3514 | 34.5603 |
| MOX0116 | 139 | 214.6 | 4.11 | 15113 | 57043 | 55.1564 | 208.1865 |
| MOX0117 | 140 | 213.6 | 3.93 | 25196 | 58949 | 96.1668 | 224.9973 |
| MOX0118 | 141 | 212.6 | 4.93 | 32015 | 82110 | 97.4099 | 249.8272 |
| MOX0119 | 142 | 211.6 | 4.39 | 29548 | 66929 | 100.9605 | 228.6853 |
| MOX0120 | 143 | 210.6 | 4.99 | 28989 | 58187 | 87.1402 | 174.9121 |
| MOX0121 | 144 | 209.6 | 3.73 | 3424 | 11404 | 13.7710 | 45.8599 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-2 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0200 | 119 | 235.79 | 3.71 | 3 | | 0.0061 | 0.0000 |
| MOX0200 | 119 | 235.79 | 4.01 | | 0 | 0.0000 | 0.0004 |
| MOX0201 | 120 | 234.79 | 3.84 | 60 | 42 | 0.1175 | 0.0818 |
| MOX0201 | 120 | 234.79 | 4.44 | | 0 | 0.0000 | 0.0005 |
| MOX0202 | 122 | 232.79 | 4.51 | 12 | | 0.0206 | 0.0000 |
| MOX0202 | 122 | 232.79 | 4.55 | | 0 | 0.0000 | 0.0005 |
| MOX0203 | 124 | 230.79 | 3.99 | 0 | 1 | 0.0012 | 0.0020 |
| MOX0203 | 124 | 230.79 | 4.03 | 0 | 0 | 0.0009 | 0.0009 |
| MOX0204 | 126 | 228.79 | 4.07 | 3 | 2 | 0.0096 | 0.0090 |
| MOX0204 | 126 | 228.79 | 3.42 | 1 | 1 | 0.0040 | 0.0028 |
| MOX0205 | 130 | 224.79 | 3.70 | 71 | 168 | 0.2885 | 0.6818 |
| MOX0205 | 130 | 224.79 | 3.46 | 76 | 169 | 0.3307 | 0.7345 |
| MOX0206 | 131 | 223.79 | 3.57 | 97 | 270 | 0.4070 | 1.1348 |
| MOX0206 | 131 | 223.79 | 3.31 | 85 | 214 | 0.3840 | 0.9715 |
| MOX0207 | 132 | 222.79 | 3.85 | 115 | 265 | 0.4478 | 1.0306 |
| MOX0207 | 132 | 222.79 | 3.70 | | 402 | | 1.6315 |
| MOX0208 | 133 | 221.79 | 3.31 | 206 | 579 | 0.9318 | 2.6243 |
| MOX0208 | 133 | 221.79 | 3.68 | 2 | 1 | 0.0089 | 0.0030 |
| MOX0209 | 134 | 220.79 | 3.99 | 296 | 1085 | 1.1113 | 4.0773 |
| MOX0209 | 134 | 220.79 | 3.67 | | 679 | | 2.7748 |
| MOX0210 | 135 | 219.79 | 4.14 | 846 | 3396 | 3.0660 | 12.3051 |
| MOX0210 | 135 | 219.79 | 3.65 | 812 | 4904 | 3.3365 | 20.1527 |
| MOX0211 | 136 | 218.79 | 3.12 | 414 | 2144 | 1.9912 | 10.3065 |
| MOX0211 | 136 | 218.79 | 3.52 | 555 | 3709 | 2.3647 | 15.8066 |
| MOX0212 | 137 | 217.79 | 4.25 | 661 | 3567 | 2.3312 | 12.5905 |
| MOX0212 | 137 | 217.79 | 3.31 | 716 | 4825 | 3.2426 | 21.8657 |
| MOX0213 | 140 | 214.79 | 4.53 | 263 | 440 | 0.8717 | 1.4571 |
| MOX0213 | 140 | 214.79 | 3.41 | 491 | 2034 | 2.1618 | 8.9463 |
| MOX0214 | 141 | 213.79 | 3.74 | 300 | 222 | 1.2032 | 0.8884 |
| MOX0214 | 141 | 213.79 | 3.19 | 254 | 89 | 1.1929 | 0.4191 |
| MOX0215 | 142 | 212.79 | 4.32 | 5342 | 12479 | 18.5470 | 43.3310 |
| MOX0215 | 142 | 212.79 | 3.45 | 3019 | 6618 | 13.1245 | 28.7730 |
| MOX0216 | 143 | 211.79 | 3.30 | 3513 | 9466 | 15.9696 | 43.0255 |
| MOX0216 | 143 | 211.79 | 3.98 | 3249 | 7968 | 12.2455 | 30.0309 |
| MOX0217 | 144 | 210.79 | 3.53 | 306 | 842 | 1.3011 | 3.5765 |
| MOX0217 | 144 | 210.79 | 2.70 | | 463 | | 2.5738 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-3 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0300 | 117 | 236.47 | 4.74 | 0 | 0 | 0.0006 | 0.0008 |
| MOX0300 | 117 | 236.47 | 4.74 | 0 | | 0.0005 | 0.0000 |
| MOX0301 | 119 | 234.47 | 3.53 | 0 | 0 | 0.0006 | 0.0006 |
| MOX0301 | 119 | 234.47 | 4.26 | 0 | | 0.0008 | 0.0000 |
| MOX0302 | 121 | 232.47 | 3.62 | 3 | 0 | 0.0056 | 0.0005 |
| MOX0302 | 121 | 232.47 | 4.15 | 2 | | 0.0044 | 0.0000 |
| MOX0303 | 123 | 230.47 | 3.91 | 2 | 1 | 0.0033 | 0.0025 |
| MOX0303 | 123 | 230.47 | 3.82 | 1 | | 0.0021 | 0.0000 |
| MOX0304 | 125 | 228.47 | 3.69 | 0 | 0 | 0.0013 | 0.0020 |
| MOX0304 | 125 | 228.47 | 3.67 | 0 | | 0.0010 | |
| MOX0305 | 127 | 226.47 | 3.89 | 36 | 50 | 0.1373 | 0.1944 |
| MOX0305 | 127 | 226.47 | 3.46 | 2 | | 0.0106 | |
| MOX0306 | 129 | 224.47 | 4.77 | 95 | 285 | 0.2993 | 0.8959 |
| MOX0306 | 129 | 224.47 | 4.08 | 33 | 228 | 0.1210 | 0.8394 |
| MOX0307 | 131 | 222.47 | 3.89 | 440 | 1695 | 1.6959 | 6.5363 |
| MOX0307 | 131 | 222.47 | 3.34 | 177 | 757 | 0.7944 | 3.3983 |
| MOX0308 | 132 | 221.47 | 4.28 | 720 | 2306 | 2.5249 | 8.0825 |
| MOX0308 | 132 | 221.47 | 4.14 | 323 | 945 | 1.1714 | 3.4225 |
| MOX0309 | 133 | 220.47 | 4.04 | 487 | 1512 | 1.8065 | 5.6155 |
| MOX0309 | 133 | 220.47 | 2.83 | 203 | 577 | 1.0747 | 3.0604 |
| MOX0310 | 134 | 219.47 | 3.46 | 546 | 2366 | 2.3675 | 10.2580 |
| MOX0310 | 134 | 219.47 | 3.68 | 377 | 1848 | 1.5364 | 7.5314 |
| MOX0311 | 135 | 218.47 | 4.14 | 1707 | 9985 | 6.1853 | 36.1765 |
| MOX0311 | 135 | 218.47 | 4.09 | 567 | 3123 | 2.0784 | 11.4530 |
| MOX0312 | 136 | 217.47 | 4.71 | 2104 | 13030 | 6.7014 | 41.4977 |
| MOX0312 | 136 | 217.47 | 3.44 | 879 | 5892 | 3.8347 | 25.6927 |
| MOX0313 | 139 | 214.47 | 3.33 | 4237 | 15654 | 19.0861 | 70.5113 |
| MOX0313 | 139 | 214.47 | 4.29 | 367 | 1356 | 1.2828 | 4.7413 |
| MOX0314 | 140 | 213.47 | 3.96 | | 0 | | 0.0006 |
| MOX0314 | 140 | 213.47 | 3.85 | 2825 | 6950 | 11.0074 | 27.0787 |
| MOX0315 | 141 | 212.47 | 4.26 | 5242 | 13733 | 18.4590 | 48.3551 |
| MOX0315 | 141 | 212.47 | 2.81 | 2500 | 6229 | 13.3478 | 33.2517 |
| MOX0316 | 142 | 211.47 | 4.02 | 4004 | 8008 | 14.9421 | 29.8822 |
| MOX0316 | 142 | 211.47 | 3.72 | | 70 | | 0.2840 |
| MOX0317 | 143 | 210.47 | 4.01 | 179 | 28 | 0.6704 | 0.1043 |
| MOX0318 | 144 | 209.47 | 4.16 | 2056 | 3426 | 7.4139 | 12.3539 |
| MOX0318 | 144 | 209.47 | 3.87 | 1178 | 1661 | 4.5667 | 6.4375 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-4 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0400 | 88 | 266.34 | 3.78 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0401 | 97 | 257.34 | 4.25 | 51 | 25 | 0.0909 | 0.0447 |
| MOX0401 | 97 | 257.34 | 3.84 | 28 | 25 | 0.0509 | 0.0458 |
| MOX0402 | 110 | 244.34 | 3.07 | 2 | 0 | 0.0049 | 0.0004 |
| MOX0402 | 110 | 244.34 | 5.24 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0403 | 114 | 240.34 | 3.71 | 2 | 1 | 0.0036 | 0.0019 |
| MOX0403 | 114 | 240.34 | 3.68 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0404 | 117 | 237.34 | 2.08 | 2 | 0 | 0.0079 | 0.0003 |
| MOX0404 | 117 | 237.34 | 4.11 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0405 | 119 | 235.34 | 3.94 | 3 | | 0.0055 | 0.0000 |
| MOX0405 | 119 | 235.34 | 4.25 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0406 | 121 | 233.34 | 4.85 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0407 | 128 | 226.34 | 4.23 | 7 | 44 | 0.0238 | 0.1577 |
| MOX0407 | 128 | 226.34 | 4.18 | 10 | 45 | 0.0328 | 0.1509 |
| MOX0408 | 130 | 224.34 | 3.84 | 10 | 37 | 0.0393 | 0.1431 |
| MOX0408 | 130 | 224.34 | 3.63 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0409 | 132 | 222.34 | 4.21 | 43 | 168 | 0.1438 | 0.5581 |
| MOX0410 | 133 | 221.34 | 3.96 | 7 | 53 | 0.0257 | 0.2005 |
| MOX0410 | 133 | 221.34 | 4.01 | 10 | 61 | 0.0361 | 0.2143 |
| MOX0411 | 134 | 220.34 | 3.91 | 215 | 1072 | 0.8230 | 4.1128 |
| MOX0411 | 134 | 220.34 | 3.87 | 357 | 1849 | 1.2938 | 6.6947 |
| MOX0412 | 135 | 219.34 | 4.22 | 814 | 4513 | 2.8949 | 16.0411 |
| MOX0412 | 135 | 219.34 | 4.01 | 708 | 3366 | 2.4719 | 11.7603 |
| MOX0413 | 136 | 218.34 | 3.86 | 1130 | 6397 | 4.3929 | 24.8594 |
| MOX0413 | 136 | 218.34 | 4.06 | 1224 | 7139 | 4.2246 | 24.6311 |
| MOX0414 | 136.5 | 217.84 | 4.10 | 554 | 2215 | 2.0268 | 8.1041 |
| MOX0414 | 136.5 | 217.84 | 3.75 | 588 | 3344 | 2.1957 | 12.4941 |
| MOX0415 | 137 | 217.34 | 4.37 | 1117 | 6421 | 3.5792 | 20.5808 |
| MOX0416 | 137.5 | 216.84 | 4.45 | 32 | 166 | 0.1088 | 0.5602 |
| MOX0416 | 137.5 | 216.84 | 3.85 | 715 | 4388 | 2.6022 | 15.9669 |
| MOX0417 | 138 | 216.34 | 4.56 | 2971 | 11465 | 9.7741 | 37.7154 |
| MOX0417 | 138 | 216.34 | 4.15 | 2491 | 9425 | 8.4099 | 31.8134 |
| MOX0418 | 139 | 215.34 | 4.05 | 4139 | 10790 | 15.3279 | 39.9628 |
| MOX0418 | 139 | 215.34 | 4.21 | 4072 | 10504 | 13.5478 | 34.9500 |
| MOX0419 | 140 | 214.34 | 3.88 | 4323 | 10595 | 16.7143 | 40.9595 |
| MOX0419 | 140 | 214.34 | 4.48 | 4122 | 10362 | 12.8887 | 32.3998 |
| MOX0420 | 141 | 213.34 | 3.94 | 3072 | 8309 | 11.6950 | 31.6320 |
| MOX0421 | 142 | 212.34 | 3.79 | 3279 | 9472 | 12.9795 | 37.4896 |
| MOX0422 | 143 | 211.34 | 4.25 | 4630 | 11896 | 16.3397 | 41.9851 |
| MOX0423 | 144 | 210.34 | 3.25 | 917 | 2042 | 4.2316 | 9.4224 |

Concentration Data for MOX-4 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. In Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0423 | 144 | 210.34 | 3.72 | 830 | 1932 | 3.1243 | 7.2750 |
| MOX0424 | 145 | 209.34 | 3.68 | 1504 | 3597 | 6.1297 | 14.6609 |
| MOX0424 | 145 | 209.34 | 4.00 | 2308 | 6217 | 8.0835 | 21.7732 |
| MOX0425 | 146 | 208.34 | 4.49 | 1594 | 5049 | 5.3262 | 16.8686 |
| MOX0425 | 146 | 208.34 | 4.01 | 1037 | 3750 | 3.6210 | 13.1019 |
| MOX0426 | 147 | 207.34 | 3.65 | 2555 | 8091 | 10.5011 | 33.2493 |
| MOX0436 | 147 | 207.34 | 3.76 | 979 | 2315 | 3.9046 | 9.2341 |
| MOX0426 | 147 | 207.34 | 3.58 | 2238 | 7119 | 8.7577 | 27.8598 |
| MOX0436 | 148 | 206.34 | 5.55 | 1943 | 4527 | 4.9044 | 11.4256 |
| MOX0427 | 148 | 206.34 | 4.70 | 2629 | 9399 | 7.8345 | 28.0111 |
| MOX0428 | 149 | 205.34 | 2.79 | 1379 | 5364 | 7.4166 | 28.8364 |
| MOX0428 | 149 | 205.34 | 3.26 | 1057 | 4215 | 4.5435 | 18.1166 |
| MOX0429 | 150 | 204.34 | 4.31 | 7426 | 18166 | 25.8439 | 63.2225 |
| MOX0429 | 150 | 204.34 | 3.96 | 6245 | 15011 | 22.0934 | 53.1016 |
| MOX0430 | 151 | 203.34 | 5.31 | 7360 | 15326 | 20.7923 | 43.2930 |
| MOX0430 | 151 | 203.34 | 4.36 | 6873 | 14071 | 22.0826 | 45.2077 |
| MOX0431 | 152 | 202.34 | 3.96 | 3575 | 6237 | 13.5402 | 23.6257 |
| MOX0431 | 152 | 202.34 | 5.11 | 6915 | 14380 | 18.9545 | 39.4151 |
| MOX0432 | 153 | 201.34 | 5.06 | 6773 | 14141 | 20.0778 | 41.9186 |
| MOX0432 | 153 | 201.34 | 3.62 | 0 | 10870 | 0.0000 | 42.0681 |
| MOX0433 | 154 | 200.34 | 4.33 | 5983 | 12398 | 20.7256 | 42.9496 |
| MOX0433 | 154 | 200.34 | 4.45 | 4907 | 9888 | 15.4451 | 31.1256 |
| MOX0434 | 155 | 199.34 | 4.07 | 2555 | 5104 | 9.4166 | 18.8113 |
| MOX0434 | 155 | 199.34 | 4.50 | 3910 | 8091 | 12.1714 | 25.1865 |
| MOX0435 | 156 | 198.34 | 4.63 | 2731 | 6859 | 8.2626 | 20.7514 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-5 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0517 | 130 | 222.42 | 3.76 | 138 | 411 | 0.5127 | 1.5300 |
| MOX0518 | 132 | 220.42 | 3.43 | 8 | 20 | 0.0311 | 0.0815 |
| MOX0519 | 134 | 218.42 | 4.38 | 10 | 10 | 0.0315 | 0.0313 |
| MOX0520 | 136 | 216.42 | 3.63 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0521 | 138 | 214.42 | 5.35 | 3592 | 12351 | 9.4040 | 32.3361 |
| MOX0522 | 140 | 212.42 | 4.01 | 320 | 921 | 1.1178 | 3.2159 |
| MOX0523 | 142 | 210.42 | 4.96 | 1994 | 5004 | 5.6317 | 14.1320 |
| MOX0524 | 144 | 208.42 | 4.01 | 0 | 3569 | 0.0000 | 12.4683 |
| MOX0525 | 146 | 206.42 | 3.76 | 3023 | 8350 | 11.2648 | 31.1124 |
| MOX0526 | 147 | 205.42 | 2.88 | 12 | 94 | 0.0565 | 0.4550 |
| MOX0527 | 148 | 204.42 | 4.14 | 10 | 69 | 0.0332 | 0.2345 |
| MOX0528 | 151 | 201.42 | 4.12 | 57 | 337 | 0.1951 | 1.1454 |
| MOX0529 | 152 | 200.42 | 4.46 | 644 | 3415 | 2.0237 | 10.7261 |
| MOX0530 | 153 | 199.42 | 4.04 | 1548 | 9003 | 5.3686 | 31.2187 |
| MOX0531 | 154 | 198.42 | 3.80 | 1559 | 7664 | 5.7490 | 28.2537 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-6 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|------|-------------------------|----------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0600 | 10 | 338.64 | 3.59 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0601 | 20 | 328.64 | 4.10 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0602 | 30 | 318.64 | 4.88 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0603 | 40 | 308.64 | 4.12 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0604 | 50 | 298.64 | 4.23 | 1 | 10 | 0.0024 | 0.0180 |
| MOX0604 | 50 | 298.64 | 4.14 | 0 | 15 | 0.0000 | 0.0254 |
| MOX0605 | 60 | 288.64 | 3.68 | 13 | 76 | 0.0272 | 0.1551 |
| MOX0605 | 60 | 288.64 | 4.00 | 30 | 190 | 0.0527 | 0.3331 |
| MOX0606 | 70 | 278.64 | 3.82 | 2 | 8 | 0.0037 | 0.0148 |
| MOX0606 | 70 | 278.64 | 3.61 | 0 | 8 | 0.0000 | 0.0161 |
| MOX0607 | 80 | 268.64 | 4.32 | 11 | 54 | 0.0181 | 0.0869 |
| MOX0608 | 90 | 258.64 | 3.93 | 551 | 2515 | 0.9817 | 4.4823 |
| MOX0609 | 94 | 254.64 | 3.16 | 10 | 11 | 0.0215 | 0.0234 |
| MOX0610 | 104 | 244.64 | 4.70 | 0 | 23 | 0.0000 | 0.0344 |
| MOX0611 | 110 | 238.64 | 4.47 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0612 | 120 | 228.64 | 3.74 | 0 | 0 | 0.001312 | 0.001797 |
| MOX0612 | 120 | 228.64 | 3.68 | 0 | 0 | 0 | 0 |
| MOX0613 | 126 | 222.64 | 5.44 | 34 | 2 | 0.0939 | 0.0045 |
| MOX0613 | 126 | 222.64 | 5.41 | 33 | 0 | 0.0858 | 0.0000 |
| MOX0614 | 130 | 218.64 | 3.67 | 76 | 0 | 0.3121 | 0.0010 |
| MOX0614 | 130 | 218.64 | 4.20 | 82 | 0 | 0.2744 | 0.0000 |
| MOX0615 | 140 | 208.64 | 3.69 | 12 | 4 | 0.0481 | 0.0154 |
| MOX0615 | 140 | 208.64 | 4.09 | 13 | 0 | 0.0430 | 0.0000 |
| MOX0620 | 141 | 207.64 | 3.91 | 14 | 24 | 0.0538 | 0.0902 |
| MOX0620 | 141 | 207.64 | 6.28 | 45 | 0 | 0.1009 | 0.0000 |
| MOX0619 | 141.5 | 207.14 | 4.49 | 36 | 5 | 0.1216 | 0.0183 |
| MOX0619 | 141.5 | 207.14 | 4.13 | 30 | 0 | 0.1014 | 0.0000 |
| MOX0616 | 145 | 203.64 | 4.27 | 30 | 3 | 0.1055 | 0.0113 |
| MOX0616 | 145 | 203.64 | 4.63 | 39 | 0 | 0.1191 | 0.0000 |
| MOX0617 | 150 | 198.64 | 4.67 | 43 | 89 | 0.1391 | 0.2866 |
| MOX0617 | 150 | 198.64 | 3.94 | 32 | 69 | 0.1134 | 0.2451 |
| MOX0618 | 154 | 194.64 | 3.57 | 6 | 3 | 0.0269 | 0.0120 |
| MOX0618 | 154 | 194.64 | 3.80 | 10 | 0 | 0.0362 | 0.0000 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (118 ft below surface)

Concentration Data for MOX-7 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0700 | 117 | 237.34 | 3.78 | | 0 | 0.0000 | 0.0003 |
| MOX0700 | 117 | 237.34 | 3.66 | 2 | 0 | 0.0043 | 0.0003 |
| MOX0701 | 119 | 235.34 | 4.05 | 0 | 0 | 0.0009 | 0.0008 |
| MOX0701 | 119 | 235.34 | 4.16 | 1 | 0 | 0.0013 | 0.0009 |
| MOX0702 | 121 | 233.34 | 3.03 | | 0 | 0.0000 | 0.0003 |
| MOX0702 | 121 | 233.34 | 3.41 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0703 | 123 | 231.34 | 3.81 | 1 | 0 | 0.0012 | 0.0009 |
| MOX0704 | 125 | 229.34 | 4.57 | 3 | 2 | 0.0094 | 0.0053 |
| MOX0704 | 125 | 229.34 | 3.82 | 1 | 1 | 0.0028 | 0.0020 |
| MOX0705 | 127 | 227.34 | 4.17 | 56 | 132 | 0.2024 | 0.4764 |
| MOX0705 | 127 | 227.34 | 3.70 | 83 | 152 | 0.3380 | 0.6155 |
| MOX0706 | 127.5 | 226.84 | 4.28 | 2 | 10 | 0.0085 | 0.0368 |
| MOX0706 | 127.5 | 226.84 | 4.14 | 3 | 14 | 0.0098 | 0.0507 |
| MOX0707 | 128 | 226.34 | 4.21 | 221 | 830 | 0.7862 | 2.9576 |
| MOX0707 | 128 | 226.34 | 3.55 | 220 | 811 | 0.9310 | 3.4285 |
| MOX0708 | 129 | 225.34 | 4.08 | 376 | 1431 | 1.3831 | 5.2613 |
| MOX0708 | 129 | 225.34 | 3.80 | 624 | 2327 | 2.4638 | 9.1849 |
| MOX0709 | 130 | 224.34 | 3.91 | 570 | 2322 | 2.1881 | 8.9069 |
| MOX0709 | 130 | 224.34 | 4.03 | 294 | 1169 | 1.0929 | 4.3520 |
| MOX0710 | 131 | 223.34 | 3.70 | 226 | 946 | 0.9151 | 3.8342 |
| MOX0710 | 131 | 223.34 | 3.71 | 312 | 992 | 1.2628 | 4.0104 |
| MOX0711 | 132 | 222.34 | 3.70 | 342 | 1740 | 1.3845 | 7.0539 |
| MOX0711 | 132 | 222.34 | 3.90 | 306 | 1516 | 1.1751 | 5.8312 |
| MOX0712 | 133 | 221.34 | 3.60 | 443 | 2040 | 1.8444 | 8.4990 |
| MOX0712 | 133 | 221.34 | 3.88 | 497 | 2519 | 1.9228 | 9.7396 |
| MOX0713 | 134 | 220.34 | 4.95 | 509 | 2890 | 1.5435 | 8.7572 |
| MOX0713 | 134 | 220.34 | 4.34 | 485 | 2836 | 1.6769 | 9.8019 |
| MOX0715 | 135 | 219.34 | 3.94 | 2 | 19 | 0.0076 | 0.0713 |
| MOX0716 | 137 | 217.34 | 4.29 | 878 | 5038 | 3.0701 | 17.6140 |
| MOX0716 | 137 | 217.34 | 3.85 | 690 | 4317 | 2.6865 | 16.8189 |
| MOX0717 | 138 | 216.34 | 4.45 | 1254 | 5557 | 4.2259 | 18.7301 |
| MOX0717 | 138 | 216.34 | 4.49 | 1318 | 5706 | 4.4017 | 19.0624 |
| MOX0718 | 139 | 215.34 | 4.43 | 2196 | 12195 | 7.4367 | 41.2915 |
| MOX0718 | 139 | 215.34 | 4.25 | 1969 | 11151 | 6.9479 | 39.3579 |
| MOX0719 | 140 | 214.34 | 3.80 | 2795 | 13444 | 11.0339 | 53.0681 |
| MOX0719 | 140 | 214.34 | 4.51 | 3108 | 15689 | 10.3362 | 52.1798 |
| MOX0720 | 141 | 213.34 | 4.30 | 2807 | 7282 | 9.7927 | 25.4013 |
| MOX0720 | 141 | 213.34 | 4.22 | 3140 | 12977 | 11.1609 | 46.1283 |
| MOX0721 | 142 | 212.34 | 3.83 | 4213 | 11052 | 16.4989 | 43.2849 |
| MOX0721 | 142 | 212.34 | 4.40 | 4681 | 12759 | 15.9593 | 43.4950 |
| MOX0722 | 143 | 211.34 | 5.10 | 4106 | 10054 | 12.0778 | 29.5716 |

Concentration Data for MOX-7 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0722 | 143 | 211.34 | 4.55 | 3677 | 9574 | 12.1236 | 31.5611 |
| MOX0723 | 144 | 210.34 | 3.82 | 445 | 1165 | 1.7475 | 4.5730 |
| MOX0723 | 144 | 210.34 | 4.05 | 2037 | 5215 | 7.5443 | 19.3133 |

Note: Soil concentrations have been corrected by a multiplier of 2.

Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-8 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0800 | 130 | 223.69 | 4.50 | | 29 | | 0.0977 |
| MOX0800 | 130 | 223.69 | 4.94 | 11 | 76 | 0.0338 | 0.2296 |
| MOX0801 | 131 | 222.69 | 3.63 | | 0 | | 0.0013 |
| MOX0801 | 131 | 222.69 | 3.59 | 3 | 0 | 0.0117 | 0.0004 |
| MOX0802 | 132 | 221.69 | 3.65 | 1 | 1 | 0.0030 | 0.0028 |
| MOX0802 | 132 | 221.69 | 3.74 | 1 | 1 | 0.0027 | 0.0020 |
| MOX0803 | 133 | 220.69 | 4.45 | 2 | 2 | 0.0084 | 0.0070 |
| MOX0803 | 133 | 220.69 | 4.31 | 2 | 1 | 0.0056 | 0.0050 |
| MOX0804 | 134 | 219.69 | 3.85 | 1 | 1 | 0.0054 | 0.0038 |
| MOX0804 | 134 | 219.69 | 4.15 | 2 | 2 | 0.0085 | 0.0062 |
| MOX0805 | 135 | 218.69 | 3.47 | 3 | 2 | 0.0112 | 0.0108 |
| MOX0805 | 135 | 218.69 | 3.97 | 2 | 1 | 0.0058 | 0.0043 |
| MOX0806 | 136 | 217.69 | 4.39 | 1 | 1 | 0.0047 | 0.0049 |
| MOX0806 | 136 | 217.69 | 4.47 | 2 | 1 | 0.0055 | 0.0045 |
| MOX0807 | 137 | 216.69 | 3.70 | 8 | 8 | 0.0341 | 0.0312 |
| MOX0807 | 137 | 216.69 | 4.20 | 8 | 5 | 0.0274 | 0.0187 |
| MOX0808 | 138 | 215.69 | 3.59 | 1 | 2 | 0.0035 | 0.0080 |
| MOX0808 | 138 | 215.69 | 4.10 | 1 | 2 | 0.0032 | 0.0064 |
| MOX0809 | 139 | 214.69 | 3.26 | 8 | 22 | 0.0361 | 0.1032 |
| MOX0809 | 139 | 214.69 | 4.11 | 9 | 19 | 0.0315 | 0.0710 |
| MOX0810 | 140 | 213.69 | 4.74 | 82 | 272 | 0.2588 | 0.8599 |
| MOX0810 | 140 | 213.69 | 4.49 | 89 | 194 | 0.2967 | 0.6478 |
| MOX0811 | 141 | 212.69 | 3.50 | 105 | 433 | 0.4490 | 1.8573 |
| MOX0811 | 141 | 212.69 | 3.80 | 122 | 461 | 0.4827 | 1.8196 |
| MOX0812 | 142 | 211.69 | 3.87 | 162 | 555 | 0.6289 | 2.1513 |
| MOX0812 | 142 | 211.69 | 3.60 | 253 | 1066 | 1.0532 | 4.4400 |
| MOX0813 | 143 | 210.69 | 3.67 | 217 | 1018 | 0.8876 | 4.1591 |
| MOX0813 | 143 | 210.69 | 3.18 | 66 | 217 | 0.3119 | 1.0258 |
| MOX0814 | 144 | 209.69 | 4.11 | 274 | 1283 | 1.0015 | 4.6836 |
| MOX0814 | 144 | 209.69 | 3.89 | 130 | 376 | 0.4994 | 1.4490 |
| MOX0815 | 145 | 208.69 | 4.73 | 318 | 1706 | 1.0070 | 5.4116 |
| MOX0815 | 145 | 208.69 | 4.13 | 234 | 1123 | 0.8504 | 4.0799 |
| MOX0816 | 147 | 206.69 | 4.67 | 3640 | 12019 | 11.6919 | 38.6042 |
| MOX0816 | 147 | 206.69 | 4.87 | 3237 | 10228 | 9.9698 | 31.5031 |
| MOX0817 | 148 | 205.69 | 4.39 | 3248 | 9717 | 11.0965 | 33.2012 |
| MOX0817 | 148 | 205.69 | 4.64 | 2913 | 8487 | 9.4158 | 27.4378 |
| MOX0818 | 149 | 204.69 | 4.34 | 3095 | 8002 | 10.6957 | 27.6554 |
| MOX0818 | 149 | 204.69 | 3.99 | 644 | 1465 | 2.4210 | 5.5071 |
| MOX0819 | 150 | 203.69 | 3.80 | 1151 | 2141 | 4.5444 | 8.4503 |
| MOX0820 | 151 | 202.69 | 4.59 | 4927 | 8949 | 16.1029 | 29.2451 |
| MOX0820 | 151 | 202.69 | 4.55 | 1861 | 3875 | 6.1361 | 12.7758 |

Concentration Data for MOX-8 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|---------|-------|----------------|--------------------|------------------------|-------|-------------------------|----------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0821 | 152 | 201.69 | 4.15 | 2086 | 2529 | 7.5408 | 9.1415 |
| MOX0821 | 152 | 201.69 | 5.02 | 1595 | 1903 | 4.7659 | 5.6860 |
| MOX0822 | 153 | 200.69 | 5.24 | 2082 | 4462 | 5.9605 | 12.7728 |
| MOX0822 | 153 | 200.69 | 5.39 | 1285 | 2761 | 3.5758 | 7.6848 |
| MOX0823 | 154 | 199.69 | 4.04 | 373 | 883 | 1.3845 | 3.2792 |
| MOX0823 | 154 | 199.69 | 4.36 | 128 | 519 | 0.4393 | 1.7868 |
| MOX0824 | 155 | 198.69 | 3.82 | 2515 | 12654 | 9.8755 | 49.6877 |
| MOX0824 | 155 | 198.69 | 3.64 | 381 | 2016 | 1.5705 | 8.3082 |
| MOX0825 | 156 | 197.69 | 3.62 | 1112 | 3936 | 4.6091 | 16.3077 |
| MOX0825 | 156 | 197.69 | 3.57 | 304 | 764 | 1.2776 | 3.2107 |
| MOX0826 | 157 | 196.69 | 4.00 | 1038 | 5023 | 3.8927 | 18.8363 |
| MOX0826 | 157 | 196.69 | 4.21 | 410 | 2029 | 1.4619 | 7.2284 |
| MOX0827 | 158 | 195.69 | 4.01 | 13980 | 31597 | 52.2950 | 118.1933 |
| MOX0827 | 158 | 195.69 | 5.48 | 7007 | 13786 | 19.1801 | 37.7366 |
| MOX0828 | 159 | 194.69 | 4.36 | 10697 | 27260 | 36.8002 | 93.7854 |
| MOX0828 | 159 | 194.69 | 4.33 | 6046 | 18886 | 20.9443 | 65.4252 |
| MOX0829 | 160 | 193.69 | 4.28 | 3535 | 8298 | 12.3895 | 29.0821 |
| MOX0829 | 160 | 193.69 | 4.44 | 1034 | 5967 | 3.4937 | 20.1601 |
| MOX0830 | 161 | 192.69 | 4.57 | 12753 | 31477 | 41.8574 | 103.3173 |
| MOX0830 | 161 | 192.69 | 5.00 | 6363 | 17015 | 19.0896 | 51.0444 |
| MOX0831 | 162 | 191.69 | 5.23 | 11148 | 26495 | 31.9720 | 75.9885 |
| MOX0831 | 162 | 191.69 | 4.38 | 4175 | 11769 | 14.2972 | 40.3038 |
| MOX0832 | 163 | 190.69 | 5.19 | 17016 | 40899 | 49.1793 | 118.2044 |
| MOX0832 | 163 | 190.69 | 5.86 | 1857 | 2396 | 4.7543 | 6.1330 |
| MOX0833 | 164 | 189.69 | 4.01 | 7082 | 20556 | 26.4903 | 76.8940 |
| MOX0833 | 164 | 189.69 | 3.08 | 0 | 0 | 0.0000 | 0.0005 |
| MOX0834 | 165 | 188.69 | 3.99 | 8855 | 21982 | 33.2905 | 82.6383 |
| MOX0834 | 165 | 188.69 | 4.19 | 4563 | 13202 | 16.3364 | 47.2613 |

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-9 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|-------------|-------|----------------|--------------------|------------------------|------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0900 | 117 | 237 | 3.92 | 0 | 0 | 0.0000 | 0.0002 |
| MOX0900 DUP | 117 | 237 | 3.8 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0901 | 119 | 235 | 4.31 | 0 | 10 | 0.0000 | 0.0182 |
| MOX0901 DUP | 119 | 235 | 3.67 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0902 | 121 | 233 | 4.13 | 0 | 9 | 0.0000 | 0.0167 |
| MOX0902 DUP | 121 | 233 | 3.97 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0903 | 123 | 231 | 3.29 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0903 DUP | 123 | 231 | 3.01 | 0 | 0 | 0.0000 | 0.0003 |
| MOX0904 | 125 | 229 | 4 | 0 | 0 | 0.0000 | 0.0000 |
| MOX0904 DUP | 125 | 229 | 2.96 | 0 | 0 | 0.0000 | 0.0005 |
| MOX0905 | 127 | 227 | 4 | 8 | 88 | 0.0315 | 0.3317 |
| MOX0905 DUP | 127 | 227 | 4.2 | 8 | 88 | 0.0298 | 0.3132 |
| MOX0906 | 128 | 226 | 3.97 | 76 | 351 | 0.2883 | 1.3244 |
| MOX0906 DUP | 128 | 226 | 4.22 | 58 | 242 | 0.2079 | 0.8593 |
| MOX0907 | 129 | 225 | 4.09 | 97 | 341 | 0.3557 | 1.2512 |
| MOX0907 DUP | 129 | 225 | 3.61 | 50 | 152 | 0.2063 | 0.6303 |
| MOX0908 | 130 | 224 | 2.84 | 92 | 268 | 0.4857 | 1.4162 |
| MOX0908 DUP | 130 | 224 | 3.45 | 63 | 154 | 0.2735 | 0.6705 |
| MOX0909 | 131 | 223 | 3.5 | 123 | 241 | 0.5292 | 1.0346 |
| MOX0909 DUP | 131 | 223 | 3.44 | 75 | 131 | 0.3284 | 0.5703 |
| MOX0910 | 132 | 222 | 3.57 | 252 | 421 | 1.0576 | 1.7690 |
| MOX0910 DUP | 132 | 222 | 3.85 | 148 | 182 | 0.5783 | 0.7076 |
| MOX0911 | 133 | 221 | 3.48 | 292 | 677 | 1.2576 | 2.9176 |
| MOX0911 DUP | 133 | 221 | 3.41 | 164 | 353 | 0.7194 | 1.5540 |
| MOX0912 | 134 | 220 | 3.69 | 631 | 1888 | 2.5652 | 7.6754 |
| MOX0912 DUP | 134 | 220 | 3.71 | 770 | 2475 | 3.1130 | 10.0076 |
| MOX0913 | 135 | 219 | 4.12 | 554 | 1329 | 2.0174 | 4.8373 |
| MOX0913 DUP | 135 | 219 | 3.9 | 332 | 728 | 1.2784 | 2.8018 |
| MOX0914 | 136 | 218 | 3.3 | 253 | 530 | 1.1496 | 2.4071 |
| MOX0914 DUP | 136 | 218 | 4.24 | 445 | 1218 | 1.5752 | 4.3078 |
| MOX0915 | 137 | 217 | 4.12 | 403 | 1004 | 1.4689 | 3.6537 |
| MOX0915 DUP | 137 | 217 | 4.06 | 237 | 647 | 0.8756 | 2.3891 |
| MOX0916 | 137.5 | 216.5 | 4.18 | 340 | 962 | 1.2186 | 3.4535 |
| MOX0916 DUP | 137.5 | 216.5 | 3.91 | 239 | 830 | 0.9169 | 3.1850 |
| MOX0917 DUP | 138 | 216 | 4.35 | 117 | 285 | 0.4047 | 0.9819 |
| MOX0918 DUP | 139 | 215 | 3.93 | 284 | 1409 | 1.0853 | 5.3777 |
| MOX0919 | 143 | 211 | 4.19 | 1174 | 5521 | 4.2037 | 19.7659 |
| MOX0919 DUP | 143 | 211 | 4.38 | 1389 | 7240 | 4.7552 | 24.7938 |
| MOX0920 | 143.5 | 210.5 | 4.55 | 1363 | 6686 | 4.4924 | 22.0427 |
| MOX0920 DUP | 143.5 | 210.5 | 5.02 | 1237 | 5647 | 3.6967 | 16.8727 |
| MOX0921 | 144 | 210 | 4.16 | 1217 | 5778 | 4.3876 | 20.8340 |

Concentration Data for MOX-9 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|-------------|-------|----------------|--------------------|------------------------|------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX0921 DUP | 144 | 210 | 4.21 | 1316 | 5349 | 4.6886 | 19.0593 |
| MOX0922 | 145 | 209 | 3.88 | 460 | 994 | 1.7784 | 3.8432 |
| MOX0922 DUP | 145 | 209 | 4.33 | 642 | 1425 | 2.2238 | 4.9349 |
| MOX0923 DUP | 146 | 208 | 3.92 | 98 | 149 | 0.3748 | 0.5704 |
| MOX0924 | 147 | 207 | 3.89 | 65 | 187 | 0.2515 | 0.7199 |
| MOX0924 DUP | 147 | 207 | 3.58 | 96 | 200 | 0.4028 | 0.8385 |
| MOX0925 | 148 | 206 | 3.87 | 350 | 1025 | 1.3572 | 3.9725 |
| MOX0925 DUP | 148 | 206 | 3.95 | 176 | 524 | 0.6675 | 1.9901 |
| MOX0926 | 149 | 205 | 3.76 | 243 | 761 | 0.9714 | 3.0364 |
| MOX0926 DUP | 149 | 205 | 3.78 | 173 | 470 | 0.6875 | 1.8658 |
| MOX0927 | 150 | 204 | 3.57 | 1081 | 4496 | 4.5415 | 18.8889 |
| MOX0927 DUP | 150 | 204 | 3.25 | 573 | 2153 | 2.6424 | 9.9360 |
| MOX0928 | 151 | 203 | 3.45 | 701 | 2503 | 3.0464 | 10.8817 |
| MOX0928 DUP | 151 | 203 | 3.98 | 1246 | 5068 | 4.6947 | 19.0990 |
| MOX0929 | 152 | 202 | 4.24 | 2164 | 8095 | 7.6567 | 28.6395 |
| MOX0929 DUP | 152 | 202 | 4.26 | 1673 | 6908 | 5.8894 | 24.3250 |

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-10 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|--------------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX1000 | 117 | 236 | 3.74 | 0 | 0 | 0.0000 | 0.0004 |
| MOX1000 DUP | 117 | 236 | 3.42 | 0 | 0 | 0.0000 | 0.0007 |
| MOX1001 | 118 | 235 | 4.06 | 35 | 20 | 0.0642 | 0.0362 |
| MOX1001 DUP | 118 | 235 | 3.92 | 0 | 0 | 0.0000 | 0.0003 |
| MOX1002 | 119 | 234 | 3.51 | 0 | 15 | 0.0000 | 0.0326 |
| MOX1002 DUP | 119 | 234 | 4.07 | 0 | 0 | 0.0000 | 0.0000 |
| MOX1003 | 120 | 233 | 3.87 | 0 | 16 | 0.0000 | 0.0305 |
| MOX1003 DUP | 120 | 233 | 3.73 | 0 | 0 | 0.0000 | 0.0000 |
| MOX1004 | 121 | 232 | 3.67 | 0 | 0 | 0.0000 | 0.0000 |
| MOX1004 DUP | 121 | 232 | 4 | 0 | 0 | 0.0000 | 0.0003 |
| MOX1005 | 122 | 231 | 3.37 | 6 | 1 | 0.0124 | 0.0027 |
| MOX1005 DUP | 122 | 231 | 3.42 | 0 | 0 | 0.0000 | 0.0011 |
| MOX1006 | 123 | 230 | 4.05 | 2 | 4 | 0.0044 | 0.0068 |
| MOX1006 DUP | 123 | 230 | 3.83 | 3 | 5 | 0.0050 | 0.0106 |
| MOX1007 | 124 | 229 | 3.32 | 0 | 2 | 0.0018 | 0.0069 |
| MOX1007 DUP | 124 | 229 | 2.8 | 1 | 4 | 0.0041 | 0.0206 |
| MOX1008 | 125 | 228 | 3.98 | 1 | 5 | 0.0020 | 0.0172 |
| MOX1008 DUP | 125 | 228 | 3.44 | 0 | 1 | 0.0016 | 0.0053 |
| MOX1009 | 126 | 227 | 3.5 | 3 | 41 | 0.0127 | 0.1776 |
| MOX1009 DUP | 126 | 227 | 3.33 | 2 | 19 | 0.0070 | 0.0859 |
| MOX1010 | 127 | 226 | 4.02 | 14 | 61 | 0.0538 | 0.2287 |
| MOX1010 DUP. | 127 | 226 | 3.98 | 19 | 62 | 0.0701 | 0.2325 |
| MOX1011 | 128 | 225 | 3.81 | 51 | 164 | 0.1999 | 0.6446 |
| MOX1011 DUP. | 128 | 225 | 3.42 | 12 | 17 | 0.0513 | 0.0728 |
| MOX1012 | 129 | 224 | 2.95 | 17 | 45 | 0.0889 | 0.2279 |
| MOX1012 DUP | 129 | 224 | 3.57 | 13 | 18 | 0.0530 | 0.0744 |
| MOX1013 | 130 | 223 | 3.65 | 8 | 11 | 0.0338 | 0.0457 |
| MOX1013 DUP. | 130 | 223 | 3.75 | 13 | 9 | 0.0534 | 0.0360 |
| MOX1014 | 131 | 222 | 4.21 | 55 | 102 | 0.1975 | 0.3619 |
| MOX1014 DUP | 131 | 222 | 3.75 | 10 | 9 | 0.0398 | 0.0377 |
| MOX1015 | 136 | 217 | 3.28 | 9 | 6 | 0.0394 | 0.0258 |
| MOX1015 DUP | 136 | 217 | 3.33 | 4 | 6 | 0.0172 | 0.0259 |
| MOX1016 | 137 | 216 | 3.36 | 17 | 25 | 0.0737 | 0.1138 |
| MOX1016 DUP. | 137 | 216 | 3.19 | 4 | 11 | 0.0200 | 0.0527 |
| MOX1017 | 138 | 215 | 4.51 | 26 | 62 | 0.0870 | 0.2057 |
| MOX1017 DUP. | 138 | 215 | 4.16 | 0 | 0 | 0.0000 | 0.0000 |
| MOX1018 | 139 | 214 | 4.11 | 30 | 110 | 0.1105 | 0.4014 |
| MOX1018 DUP. | 139 | 214 | 3.87 | 18 | 50 | 0.0684 | 0.1928 |
| MOX1019 | 140 | 213 | 4.43 | 1256 | 2944 | 4.2544 | 9.9667 |
| MOX1019 DUP. | 140 | 213 | 4.11 | 892 | 1908 | 3.2548 | 6.9653 |
| MOX1020 | 141 | 212 | 4.42 | 2670 | 10185 | 9.0602 | 34.5644 |

Concentration Data for MOX-10 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|--------------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX1020 DUP. | 141 | 212 | 4.31 | 2904 | 7439 | 10.1053 | 25.8892 |
| MOX1021 | 142 | 211 | 4.13 | 2248 | 8783 | 8.1659 | 31.9002 |
| MOX1021 DUP. | 142 | 211 | 4.38 | 1628 | 2815 | 5.5767 | 9.6392 |
| MOX1022 | 143 | 210 | 4.65 | 1709 | 6588 | 5.5125 | 21.2504 |
| MOX1022 DUP. | 143 | 210 | 3.99 | 284 | 342 | 1.0669 | 1.2851 |
| MOX1023 | 144 | 209 | 4.01 | 1308 | 3375 | 4.8930 | 12.6242 |
| MOX1023 DUP. | 144 | 209 | 4.41 | 958 | 1240 | 3.2583 | 4.2184 |
| MOX1024 | 145 | 208 | 4.55 | 1824 | 5046 | 6.0140 | 16.6350 |
| MOX1024 DUP. | 145 | 208 | 3.95 | 1110 | 2287 | 4.2137 | 8.6851 |
| MOX1025 | 146 | 207 | 3.79 | 458 | 1133 | 1.8131 | 4.4823 |
| MOX1025 DUP. | 146 | 207 | 3.84 | 342 | 689 | 1.3355 | 2.6895 |
| MOX1026 | 147 | 206 | 3.7 | 1227 | 5294 | 4.9741 | 21.4603 |
| MOX1026 DUP. | 147 | 206 | 4.01 | 1661 | 3320 | 6.2125 | 12.4177 |
| MOX1027 | 148 | 205 | 3.44 | 2800 | 10097 | 12.2079 | 44.0267 |
| MOX1027 DUP. | 148 | 205 | 3.61 | 553 | 912 | 2.2983 | 3.7877 |
| MOX1028 | 149 | 204 | 3.36 | 656 | 5121 | 2.9302 | 22.8617 |
| MOX1028 DUP. | 149 | 204 | 3.41 | 547 | 2643 | 2.4047 | 11.6269 |
| MOX1029 DUP. | 150 | 203 | 3.72 | 649 | 2018 | 2.6155 | 8.1367 |
| MOX1030 | 151 | 202 | 4.08 | 1627 | 8208 | 5.9811 | 30.1755 |
| MOX1030 DUP. | 151 | 202 | 3.78 | 1247 | 5872 | 4.9473 | 23.3034 |
| MOX1031 | 152 | 201 | 3.52 | 1518 | 7013 | 6.4685 | 29.8830 |
| MOX1031 DUP. | 152 | 201 | 3.72 | 742 | 2598 | 2.9900 | 10.4758 |
| MOX1032 | 153 | 200 | 4.55 | 2329 | 9226 | 7.6766 | 30.4164 |
| MOX1032 DUP. | 153 | 200 | 4.52 | 1999 | 7657 | 6.6325 | 25.4094 |

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

Concentration Data for MOX-11 Soil Boring Samples

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|----------------|-------|----------------|--------------------|------------------------|------|-------------------------|--------|
| | | | | TCE | PCE | TCE | PCE |
| MOX01100 | 117 | 237 | 4.45 | 0 | 0 | 0.0006 | 0.0006 |
| MOX01100 DUP | 117 | 237 | 3.26 | 0 | 0 | 0.0000 | 0.0007 |
| MOX01101 | 118 | 236 | 3.67 | 0 | 0 | 0.0000 | 0.0008 |
| MOX01101 DUP | 118 | 236 | 3.3 | 0 | 1 | 0.0000 | 0.0012 |
| MOX01102 | 119 | 235 | 3.93 | 0 | 1 | 0.0005 | 0.0015 |
| MOX01102 DUP | 119 | 235 | 3.29 | 0 | 0 | 0.0000 | 0.0003 |
| MOX01103 | 121 | 233 | 4.33 | 0 | 0 | 0.0000 | 0.0003 |
| MOX01103 DUP | 121 | 233 | 3.59 | 0 | 1 | 0.0000 | 0.0016 |
| MOX01104 | 122 | 232 | 3.36 | 0 | 0 | 0.0000 | 0.0002 |
| MOX01104 DUP | 122 | 232 | 3.19 | 0 | 0 | 0.0000 | 0.0006 |
| MOX01105 | 123 | 231 | 3.02 | 0 | 0 | 0.0000 | 0.0002 |
| MOX01105 DUP | 123 | 231 | 4.01 | 0 | 0 | 0.0000 | 0.0004 |
| MOX01106 | 124 | 230 | 3.07 | 0 | 0 | 0.0000 | 0.0004 |
| MOX01106 DUP | 124 | 230 | 3.38 | 0 | 0 | 0.0000 | 0.0009 |
| MOX01107 | 125 | 229 | 3.49 | 0 | 0 | 0.0000 | 0.0005 |
| MOX01107 DUP | 125 | 229 | 3.25 | 0 | 0 | 0.0000 | 0.0000 |
| MOX01108 | 126 | 228 | 3.27 | 0 | 0 | 0.0000 | 0.0006 |
| MOX01108 DUP. | 126 | 228 | 3.24 | 0 | 0 | 0.0000 | 0.0006 |
| MOX01109 | 127 | 227 | 3.24 | 1 | 1 | 0.0043 | 0.0057 |
| MOX01109 DUP. | 127 | 227 | 3.44 | 0 | 0 | 0.0000 | 0.0007 |
| MOX01110 | 128 | 226 | 3.4 | 0 | 0 | 0.0000 | 0.0020 |
| MOX01110 DUP. | 128 | 226 | 3.36 | 0 | 0 | 0.0000 | 0.0007 |
| MOX01111 | 129 | 225 | 3.75 | 0 | 1 | 0.0012 | 0.0030 |
| MOX01111 DUP. | 129 | 225 | 3.72 | 0 | 1 | 0.0018 | 0.0029 |
| MOX01112 | 130 | 224 | 3.7 | 6 | 16 | 0.0260 | 0.0648 |
| MOX01112 DUP. | 130 | 224 | 3.75 | 3 | 6 | 0.0102 | 0.0245 |
| MOX01113 | 131 | 223 | 2.36 | 21 | 79 | 0.1364 | 0.5005 |
| MOX01113 DUP.. | 131 | 223 | 3.47 | 11 | 38 | 0.0496 | 0.1658 |
| MOX01114 | 132 | 222 | 3.31 | 42 | 158 | 0.1895 | 0.7141 |
| MOX01114 DUP. | 132 | 222 | 3.39 | 21 | 46 | 0.0929 | 0.2037 |
| MOX01115 | 133 | 221 | 3.19 | 212 | 949 | 0.9966 | 4.4642 |
| MOX01115 DUP. | 133 | 221 | 3.34 | 121 | 514 | 0.5416 | 2.3064 |
| MOX01116 | 134 | 220 | 3.56 | 183 | 668 | 0.7706 | 2.8141 |
| MOX01116 DUP. | 134 | 220 | 3.51 | 52 | 107 | 0.2240 | 0.4576 |
| MOX01117 | 135 | 219 | 3.84 | 135 | 400 | 0.5261 | 1.5634 |
| MOX01117 DUP. | 135 | 219 | 4.28 | 48 | 81 | 0.1668 | 0.2824 |
| MOX01118 | 136 | 218 | 3.11 | 0 | 0 | 0.0000 | 0.0000 |
| MOX01118 DUP. | 136 | 218 | 3.26 | 179 | 736 | 0.8221 | 3.3859 |
| MOX01119 | 137 | 217 | 3.36 | 260 | 1157 | 1.1615 | 5.1644 |
| MOX01119 DUP. | 137 | 217 | 3.55 | 121 | 301 | 0.5123 | 1.2712 |
| MOX01120 | 138 | 216 | 3.95 | 84 | 229 | 0.3194 | 0.8710 |

Concentration Data for MOX-11 Soil Boring Samples (continued)

| Sample | Depth | Elev. (msl) | Soil wt (grams) | Aqueous Conc. (PPB) | | Conc. in Soil (ug/g) | |
|----------------|-------|----------------|--------------------|------------------------|-------|-------------------------|---------|
| | | | | TCE | PCE | TCE | PCE |
| MOX01120 DUP. | 138 | 216 | 4.13 | 85 | 247 | 0.3103 | 0.8988 |
| MOX01121 | 141 | 213 | 3.27 | 197 | 275 | 0.9042 | 1.2632 |
| MOX01121 DUP. | 141 | 213 | 3.29 | 260 | 375 | 1.1863 | 1.7080 |
| MOX01122 | 142 | 212 | 4.2 | 555 | 845 | 1.9834 | 3.0196 |
| MOX01122 DUP. | 142 | 212 | 3.52 | 221 | 219 | 0.9431 | 0.9336 |
| MOX01123 | 143 | 211 | 3.34 | 52 | 130 | 0.2347 | 0.5839 |
| MOX01123 DUP. | 143 | 211 | 3.45 | 30 | 36 | 0.1317 | 0.1585 |
| MOX01124 | 144 | 210 | 3.99 | 32 | 74 | 0.1184 | 0.2786 |
| MOX01124 DUP. | 144 | 210 | 5.06 | 32 | 37 | 0.0940 | 0.1098 |
| MOX01125 | 145 | 209 | 4.33 | 184 | 287 | 0.6360 | 0.9933 |
| MOX01125 DUP. | 145 | 209 | 3.73 | 69 | 73 | 0.2781 | 0.2918 |
| MOX01126 | 146 | 208 | 3.32 | 404 | 958 | 1.8242 | 4.3281 |
| MOX01126 DUP. | 146 | 208 | 3.43 | 212 | 322 | 0.9279 | 1.4077 |
| MOX01127 | 147 | 207 | 3.64 | 111 | 383 | 0.4575 | 1.5792 |
| MOX01127 DUP. | 147 | 207 | 3.52 | 83 | 243 | 0.3542 | 1.0346 |
| MOX01128 | 148 | 206 | 3.51 | 701 | 1363 | 2.9958 | 5.8248 |
| MOX01128 DUP.. | 148 | 206 | 3.27 | 422 | 434 | 1.9339 | 1.9929 |
| MOX01129 | 149 | 205 | 2.7 | 126 | 186 | 0.6977 | 1.0328 |
| MOX01129 DUP. | 149 | 205 | 2.44 | 72 | 91 | 0.4431 | 0.5589 |
| MOX01130 | 150 | 204 | 3.34 | 1578 | 7850 | 7.0882 | 35.2550 |
| MOX01130 DUP. | 150 | 204 | 3.15 | 1298 | 5957 | 6.1796 | 28.3678 |
| MOX01131 | 151 | 203 | 3.63 | 1678 | 5628 | 6.9336 | 23.2543 |
| MOX01131 DUP. | 151 | 203 | 3.44 | 1221 | 3046 | 5.3252 | 13.2810 |
| MOX01132 | 152 | 202 | 3.32 | 4005 | 10418 | 18.0957 | 47.0699 |
| MOX01132 DUP. | 152 | 202 | 3.47 | 3418 | 7184 | 14.7733 | 31.0545 |
| MOX01133 | 153 | 201 | 3.37 | 3254 | 8347 | 14.4819 | 37.1522 |
| MOX01133 DUP. | 153 | 201 | 3.28 | 2809 | 4160 | 12.8456 | 19.0244 |
| MOX01134 | 154 | 200 | 3.19 | 5237 | 12837 | 24.6236 | 60.3606 |
| MOX01134 DUP. | 154 | 200 | 3.3 | 3407 | 5922 | 15.4884 | 26.9184 |
| MOX01135 | 155 | 199 | 3.6 | 4506 | 11455 | 18.7738 | 47.7305 |
| MOX01135 DUP. | 155 | 199 | 3.01 | 2825 | 6387 | 14.0763 | 31.8273 |
| MOX01136 | 156 | 198 | 3.1 | 274 | 545 | 1.3252 | 2.6366 |
| MOX01136 DUP. | 156 | 198 | 3.08 | 1111 | 2583 | 5.4088 | 12.5804 |

Note: Soil concentrations have been corrected by a multiplier of 2.
Only corrected those below water table (124 ft below surface)

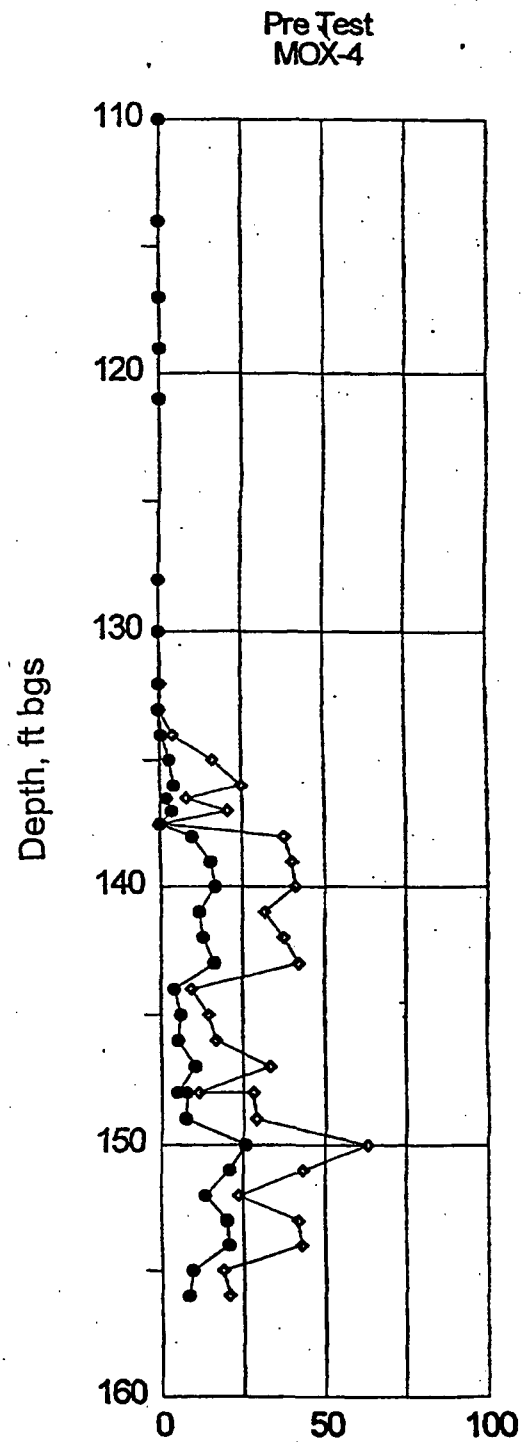
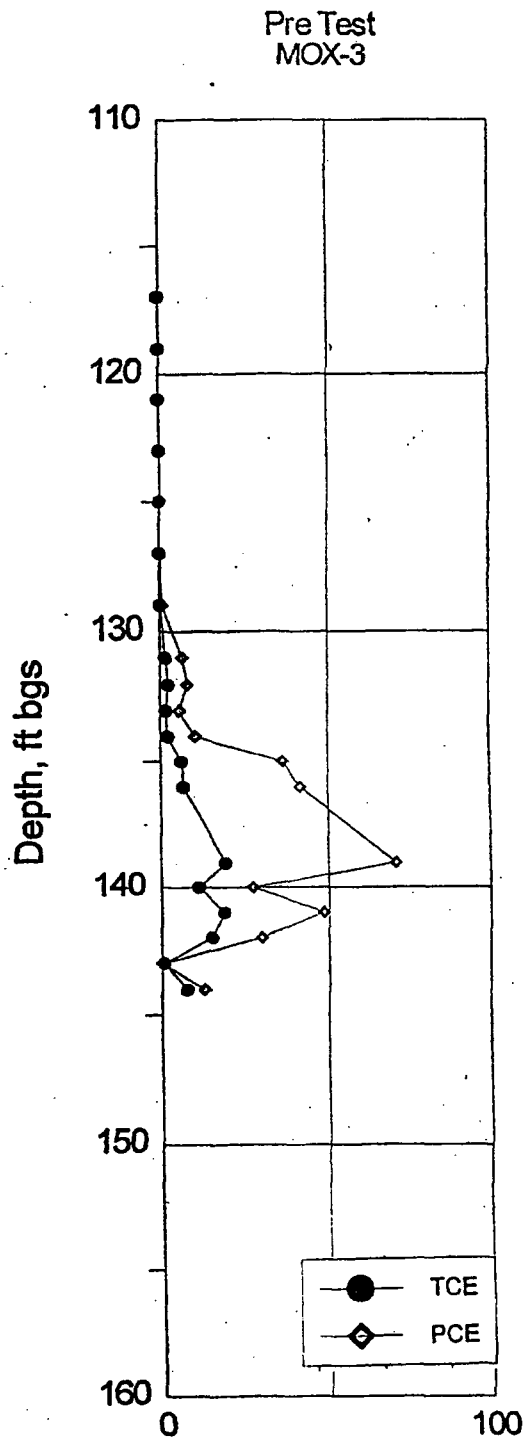
Monitoring Well Water Concentrations

| Sample Date | MOX-5, mg/L | | MOX-7, mg/L | | MOX-8, mg/L | |
|----------------|-------------|-------|-------------|-------|-------------|-------|
| | PCE | TCE | PCE | TCE | PCE | TCE |
| 03/01/97 | 142.52 | 27.84 | 151.19 | 24.81 | 159.71 | 25.30 |
| 03/20/97 | 106.28 | 21.73 | 117.34 | 21.67 | 155.15 | 23.18 |
| 04/15/97 | 98.11 | 19.84 | 101.13 | 17.07 | 76.57 | 14.16 |
| 04/17/97 | 40.33 | 16.68 | 38.93 | 8.78 | 29.41 | 7.05 |
| 04/18/97 | 47.41 | 15.81 | 18.46 | 4.28 | 18.43 | 2.52 |
| 04/19/97 | 19.94 | 6.97 | 15.13 | 4.21 | 14.60 | 2.62 |
| 04/21/97 | | | | | 0.01 | 0.00 |
| 04/22/97 | 0.35 | 0.01 | 0.00 | 0.00 | 1.59 | 0.19 |
| 04/25/97 | 0.48 | 0.02 | 1.46 | 0.04 | 13.32 | 4.01 |
| 04/30/97 | 1.84 | 0.17 | 13.88 | 2.82 | 30.53 | 8.75 |
| 05/07/97 | 2.19 | 0.56 | 31.07 | 6.04 | 46.15 | 8.79 |
| 05/14/97 | 1.74 | 0.47 | 32.04 | 7.30 | 63.48 | 11.24 |
| 05/21/97 | 2.33 | 0.63 | 40.97 | 8.73 | 78.42 | 12.28 |
| 05/29/97 | 4.67 | 1.42 | 42.05 | 9.24 | 78.29 | 12.84 |
| 06/04/97 | 2.61 | 0.66 | 42.10 | 9.92 | 77.95 | 13.47 |
| 06/11/97 | 8.71 | 2.93 | 53.20 | 11.78 | 84.79 | 13.66 |
| 06/25/97 | 10.87 | 3.85 | 67.44 | 14.24 | 108.16 | 17.09 |
| 07/09/97 | 11.99 | 4.46 | 52.99 | 12.24 | 87.82 | 15.25 |

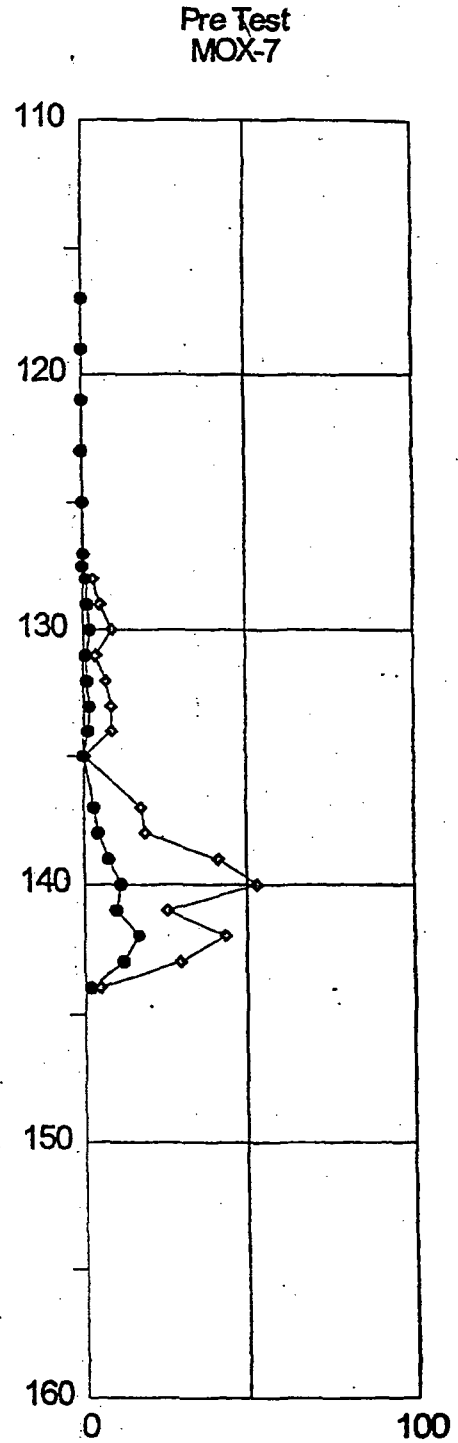
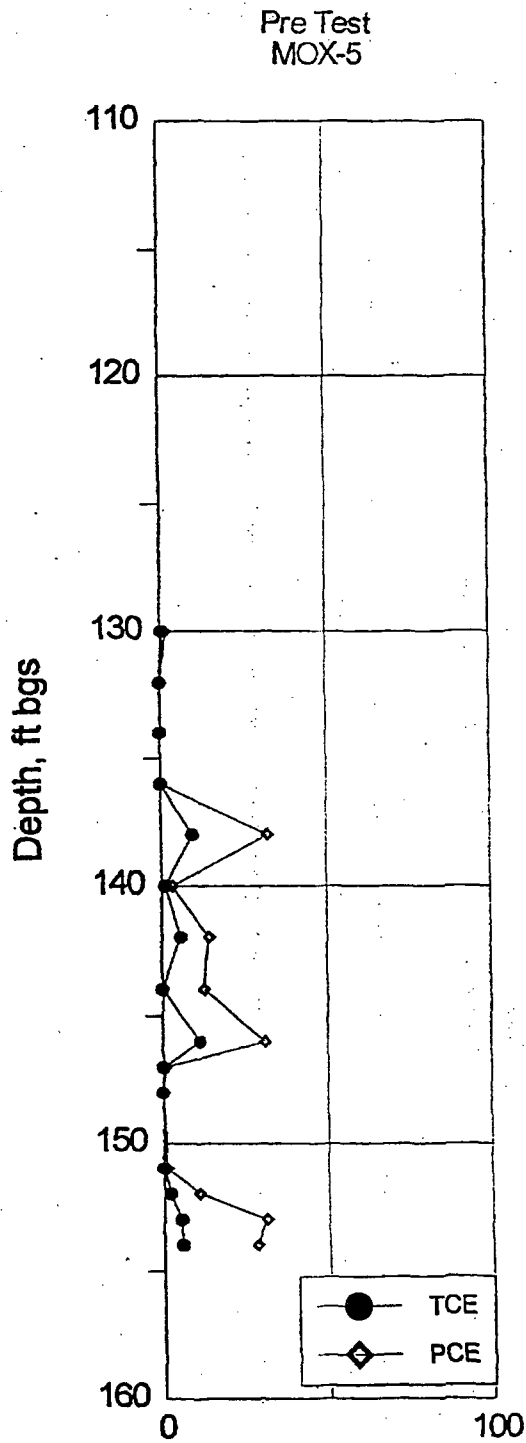
Monitoring Well Chloride and Nitrate Data

| Sample Date | MOX-5, mg/L | | MOX-7, mg/L | | MOX-8, mg/L | |
|----------------|-------------|---------|-------------|---------|-------------|---------|
| | Chloride | Nitrate | Chloride | Nitrate | Chloride | Nitrate |
| 4/3/97 | 2.75 | 19.99 | 3.69 | 12.89 | 4.40 | 19.85 |
| 4/17/97 | 5.56 | 48.50 | 5.20 | 28.47 | 4.85 | 32.10 |
| 4/18/97 | 5.54 | 50.62 | 10.61 | 32.93 | 31.30 | 37.60 |
| 4/19/97 | 9.57 | 65.67 | 7.67 | 38.14 | 22.05 | 32.76 |
| 4/21/97 | | | | | 16.29 | 36.65 |
| 4/22/97 | 19.69 | 49.87 | 37.61 | 41.57 | 15.70 | 32.16 |
| 4/25/97 | 18.54 | 41.46 | 23.02 | 32.31 | 9.67 | 30.71 |
| 5/14/97 | 5.09 | 43.17 | 5.61 | 14.87 | 6.40 | 21.90 |
| 5/21/97 | 5.57 | 36.41 | 7.64 | 14.36 | 9.16 | 20.99 |
| 5/29/97 | 9.60 | 34.48 | 6.49 | 13.71 | 6.01 | 21.73 |
| 6/4/97 | 10.36 | 30.90 | 5.67 | 13.39 | 7.76 | 20.89 |

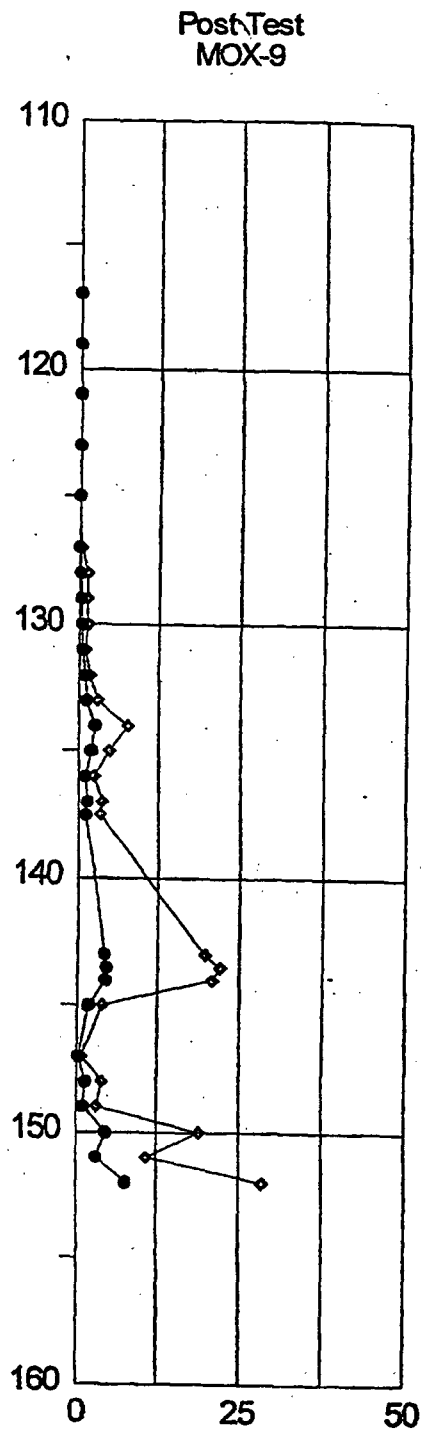
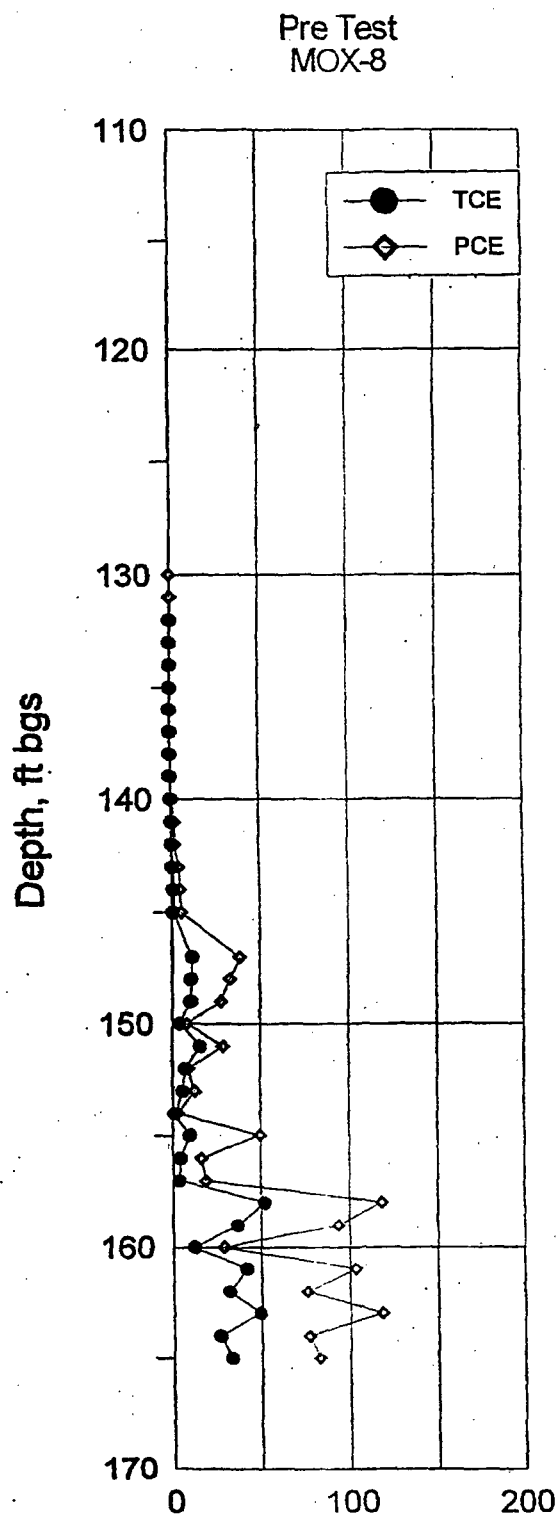
Soil Concentration Depth Profiles for MOX-3 and MOX-4 Borings



Soil Concentration Depth Profiles for MOX-5 and MOX-7 Borings

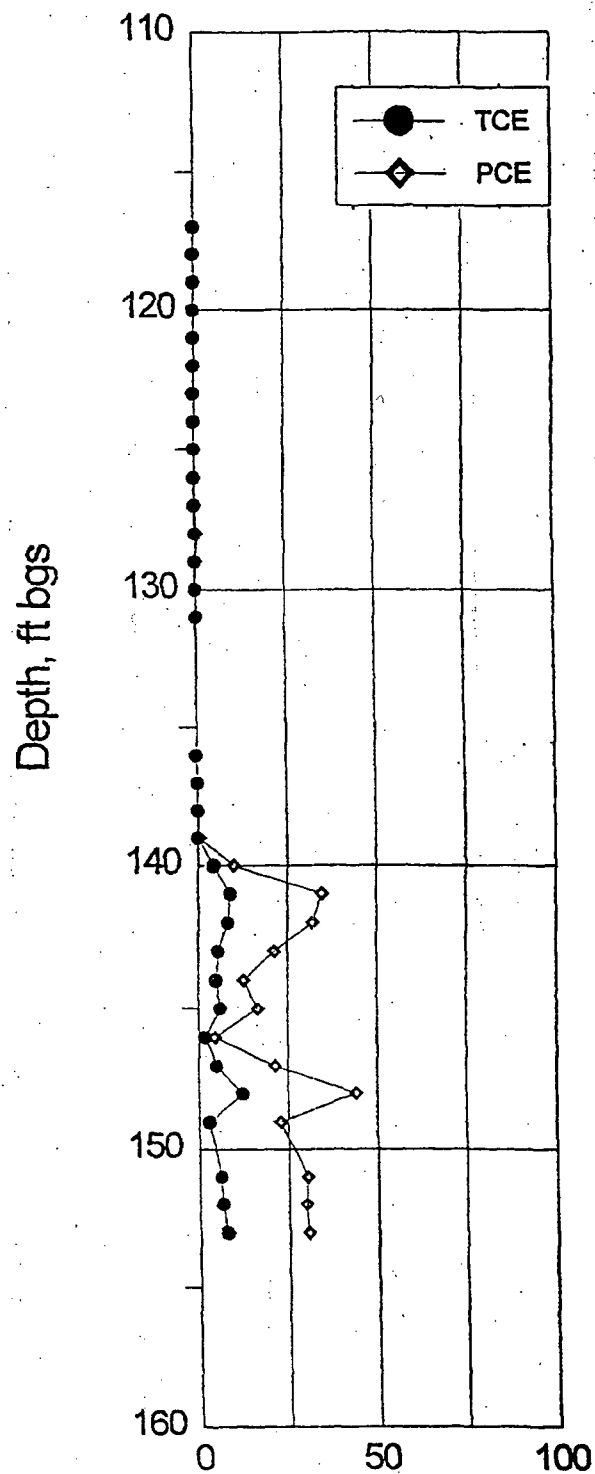


Soil Concentration Depth Profiles for MOX-8 and MOX-9 Borings



Soil Concentration Depth Profiles for MOX-10 Borings

Post Test
MOX-10



Calculation of DNAPL Volume in Treatment Zone

Definitions:

Treatment zone area is circular with a radius, r , of 27 feet (824 cm) (distance from center injector to monitoring wells)

Treatment zone total height, h_T , is from the top of the Green Clay to the water table: Height (h_T) of 30 feet is based on average depth of water table at 125 ft bgs. and average depth of Green Clay at 155 ft bgs. h_i are the 1 foot (30.5 cm) increments from the Green Clay to the water table.

ρ = bulk soil density, in gm/cc = 2.1 gm/cc for soil at demonstration site

V_i = Volume over the depth interval i , in cubic centimeters (cc)

$C_{avg,i}$ = average concentration over the depth interval i , in μg of contaminant per gram of soil

$$\text{Total Volume in } \mu\text{g} = V_T = \sum_{i=0}^{30} \rho V_i (C_{TCE, avg, i} + C_{PCE, avg, i}) = \sum_{i=0}^{30} \rho \pi r^2 h_i (C_{TCE, avg, i} + C_{PCE, avg, i})$$

$$\text{Total Volume in pounds} = \text{Volume in } \mu\text{g} * 10^{-9} \text{ kg}/\mu\text{g} * 2.2 \text{ pounds}/\text{kg}$$

Calculation of DNAPL Destroyed

$$\text{DNAPL destroyed} = V_{T, \text{pre-test}} - V_{T, \text{post-test}}$$

APPENDIX B

SAMPLING AND ANALYSIS METHODS

Sediment Samples

Once the core was brought to the surface, a 2 cc plug sample was collected using a modified plastic syringe. The plug was transferred to a 22 ml vial containing 5 ml of nano-pure water and the vial was sealed with a crimped septum top for later head space analysis. Duplicate samples were collected at each depth and all samples were stored at 4°C until analysis.

Each sample was weighed and then analyzed on the HP 5890 Series gas chromatograph using an automated head space sampler for equivalent water concentrations. Mass soil concentrations (ppb, µg/kg) were calculated based on an equal head space volume from 7.5 ml of water standards and approximately 7.5 ml of water/soil matrix and were corrected for the mass difference between the soil and water. The gas chromatograph was calibrated using certified solvent mixtures in methanol diluted to specific concentrations. The standard concentrations used for each head space sample run were 3, 5, 10, 50, 250, 500, and 1,000 ppb (µg/l). The samples were analyzed for Vinyl Chloride, Freon-11, Freon-113, 1,1-DCE, trans-DCE, cis-DCE, 1,1,1-TCA, CCl₄, TCE, and PCE.

Water Samples

The Savannah River Technology Center's technique used to sample and analyze water samples for VOC content is a modified version of EPA Method 3810 and has been studied and used successfully at SRS since 1991. A water level measurement was taken and minimum of 30 gallons of groundwater was purged from each well. Temperature and pH were measured using an electronic probe. 7.5 ml of groundwater was transferred from the well sample port to a 22 ml glass head space vial and the vial was sealed with a crimped Teflon-lined septum top for head space analysis. 40 ml plastic vials were filled for chloride ion analysis. Duplicate samples were collected at each well and all samples were stored at 4°C until analysis (maximum allowed storage time is 14 days).

Each VOC sample was analyzed on a HP 5890 Series II gas chromatograph (GC) using an automated head space sampler at 70°C for water contaminant concentrations. The GC is equipped with an electron capture detector (ECD) and flame ionization detector (FID) connected in parallel. The GC column is a Supelco - VOCOL megabore borosilicate glass (60m x 0.75 mm ID x 1.5 micron film thickness) specifically developed for volatile priority pollutants (EPA Methods 502, 602, and 8240). The GC is calibrated using certified solvent mixtures in methanol diluted to specific concentrations and two reagent blanks. The standard concentrations used for each head space sample run were 3, 5, 10, 50, 250, 500, and 1,000 ppb (µg/l). The samples were analyzed for Vinyl Chloride, Freon-11, Freon-113, 1,1-DCE, trans-DCE, cis-DCE, 1,1,1-TCA, CCl₄, TCE, and PCE.

Groundwater samples were analyzed for nutrients using a Dionex QIC 2 ion chromatograph. A FAST ANION (P/N 39590, 4x250mm) ion exchange column equipped with polymeric packing was used for separation of chloride, nitrite, nitrate, phosphate and sulfate. A conductivity detector measuring µS was used. The ions were eluted with a 200 mM Na₂CO₃ / 75 mM NaHCO₃ solution at a flow rate of 2 ml/min.

Standards were prepared using solutions of sodium chloride, sodium nitrate, sodium nitrite, potassium phosphate, and potassium sulfate. The standards were made at several different concentrations in order to generate an acceptable calibration curve. The calibration data was entered into the Dionex AI450 software package and configured to automatically calculate concentrations. The software was configured to automatically generate a report listing the component name, retention time, concentration in mg/l, area of response, and peak characteristics.

APPENDIX C

BASIS FOR UNIT COST FOR PUMP AND TREAT SYSTEM



Department of Energy
Savannah River Operations Office
P.O. Box A
Aiken, South Carolina 29802

WSRC-TR-97-00283
September 19, 1997
Rev. 0
Page C-2

SEP 03 1996

Mr. John L. Steele, Manager
Manager, Focus Area Programs Department
Westinghouse Savannah River Company
P. O. Box 616
Aiken, SC 29802

Dear Mr. Steele:

SUBJECT: Cost Savings Analyses for Soil Vapor Extraction (SVE) (U)

A second independent analysis of projected and actual costs for the subject activity was performed by this office as a result of the meeting held on August 21 between your staff and Terry Brennan of this office.

This analysis supports your claim for comparing the new technology, SVE, to the cost of removing the same amount of solvent with the baseline pump and treat technology, the M-1 Air Stripper. The resulting savings for the solvent extracted by the SVE during the first twelve months of operation is \$4,380,000.

Questions from you or your staff may be directed to Terry Brennan at 725-4716.

Sincerely,


Karen L. Hooker, Director
Program Management and
Coordination Division

PM&CD:TJB:ap

OB-96-018

cc:
G. Hooker, WSRC, 773-41A
J. Iwert, WSRC, 773-41A

400338

Westinghouse Savannah River Company WSRC-TR-97-00283
September 19, 1997
INTER-OFFICE MEMORANDUM Rev. 0
Page C-3

July 30, 1996

SRT-FAP-96-0173

To: J. L. Steele

From: G. J. Hooker *GJH*
 J. W. Iwert

**ESTIMATED COST SAVINGS
SOIL VAPOR EXTRACTION COMPARED TO PUMP AND TREAT AND
IN WELL VAPOR STRIPPING COMPARED TO PUMP AND TREAT**

SUMMARY

This document details FY1996 cost savings attributable to Soil Vapor Extraction (\$4,380,000) and to In Well Vapor Stripping (\$2,462,000). These savings are derived by comparing the new technology to the cost of removing the same amount of solvent with the baseline pump and treat technology, the M-1 air stripper. Soil Vapor Extraction (SVE) removes the solvent from the vadose zone before it has migrated to the groundwater and avoids the greater cost of removal by pump and treat. In Well Vapor Stripping (IWVS) is being applied in the Southern Sector of the A/M contaminant plume to remove solvent from groundwater at low solvent concentrations where the economic advantage of IWVS over Pump and Treat is most significant.

The capital and O & M cost estimates were provided by the WSRC Site Project Cost Estimating Department. Technical input and review was provided by Roger White of SRTC and by Chris Bergren and Michael Hartz of WSRC-ER.

DISCUSSION

Soil Vapor Extraction

Four Soil Vapor Extraction units with catalytic oxidation were started up in A/M Area in May 1995. Although this innovative technology was anticipated in the 1993 Baseline its first full year of operation was completed in April 1996. We are therefore submitting the cost savings attributable to SVE for the FY1996 Award Fee Item.

It is estimated that over 1 million pounds of the solvent contaminant in the A/M Area plume remains in the vadose zone where it will continue to recharge the groundwater. Removal of the contaminant from the soil is less expensive than removal from the groundwater.

Exhibit I summarizes the full operating cost for removing 64,800 lbs of solvent (\$18.90 per lb) with the SVE units during the most recent 12 months, the full operating cost for removing 13,209 lbs of solvent (\$86.49 per lb) extracted by the M-1 air stripper for a similar period, and calculates the resulting savings for the solvent extracted by the SVE in this period, \$4,380,000.

In Well Vapor Stripping

The scope for this project is detailed in "Southern Sector Vertical Recirculation Wells-Phases 2 and 3", G-TC-A-0006. As a substitute for pump and treat remediation, a line of 12 Vertical Recirculation wells is being installed at the southernmost extent of the A/M Area plume to terminate its further migration and to remove the contaminant from the plume as it moves past the line of wells. Exhibit II summarizes the full cost per pound of solvent removal by IWVS (\$74.94 per lb), the adjusted cost per pound of solvent removal for the M-1 stripper operating in the low solvent concentration of the southern sector (\$1210.86 per lb), and the cost savings per pound of solvent removed by the IWVS (\$1135.92 per lb). The resulting FY1996 savings estimate is \$2,462,000.

Exhibit III is the June ER solvent removal summary report from which solvent removal rates were taken.

Exhibit IV is the Estimate Detail Sheet for Capital and O&M costs for the M-1 Stripper, the Soil Vapor Extraction, and the In Well Vapor Stripping. These calculations are further supported in the following Exhibits.

Capital costs for the pump and treat operation were estimated from the following document by Stone and Webster (and approved by DOE), "Pump and Treat of Contaminated Groundwater at USDOE Savannah River Site, Aiken, SC, June 1994. Exhibit V is the information used. Note that because the M-1 stripper is being modified to treat the offgas at a cost of \$449,000 this amount has been added to the final estimate for the M-1 stripper capital cost.

Exhibit VI is the final capitalized amount for the SVE operation.

Exhibit VII is the capital cost and other data provided for the IWVS cost estimate.

Exhibit VIII contains other miscellaneous notes and data sheets used in this estimate.

EXHIBIT I
ESTIMATED COST SAVINGS
SOIL VAPOR EXTRACTION COMPARED WITH PUMP AND TREAT

ANNUAL OPERATING COST FOR FOUR M AREA SVE UNITS:

| | |
|---------|-------------|
| Capital | \$260,000 |
| O & M | \$964,000 |
| Total | \$1,224,600 |

SOLVENT REMOVED BY THESE SVE UNITS, 6/95 THRU 5/96..... 64,800 lbs

SVE COST PER POUND EXTRACTED:

$\$1,224,600 / 64,800 \text{ lbs} = \18.90

ANNUAL OPERATING COST FOR M-1 AIR STRIPPER:

| | |
|---------|-------------|
| Capital | \$172,500 |
| O & M | \$970,000 |
| Total | \$1,142,500 |

SOLVENT REMOVED BY M-1 AIR STRIPPER, 5/95 THRU 4/96..... 13,209 lbs

M-1 COST PER POUND EXTRACTED:

$\$1,142,500 / 13,209 \text{ lbs} = \86.49

COST SAVINGS BY SVE:

$(\$86.49 - \$18.90) \times 64,800 \text{ lbs} = \$67.59 \times 64,800 \text{ lbs} = \$4,379,832$

Rounding..... 168
\$4,380,000

EXHIBIT II
ESTIMATED COST SAVINGS
INWELL VAPOR STRIPPING COMPARED WITH PUMP AND TREAT

ANNUAL OPERATING COST FOR INWELL VAPOR STRIPPING (IWVS):

| | |
|--------------|-----------|
| Capital..... | \$62,400 |
| O & M..... | \$100,000 |
| Total..... | \$162,400 |

ESTIMATED ANNUAL SOLVENT REMOVAL FOR IWVS: $0.0217 \text{ lbs/hr} \times 12 \text{ wells} \times 24 \text{ hrs/day} \times 365 \text{ days/year} \times 0.95 \text{ availability} = 2167 \text{ lbs/year}$ **COST PER POUND OF SOLVENT REMOVED BY IWVS:** $\$162,400 / 2167 \text{ lbs} = \74.94 per lb **COST OF REMOVING SOLVENT FROM THE IWVS FEEDSTREAM WITH M-1 STRIPPER:**

From Exhibit I the operating cost of M-1 Stripper.....\$86.49 per lb

Concentration of Solvent in M-1 Feedstream is.....7 ppm

Concentration of Solvent in IWVS Feedstream is.....0.5 ppm

Cost of Operating M-1 in the IWVS Feedstream: $(7 \text{ ppm} / 0.5 \text{ ppm}) \times \$86.49 = 14 \times \$86.49 = \1210.86 per lb **ESTIMATED COST SAVINGS FOR THE IWVS:** $(\$1210.86 - \$74.94) \times 2167 \text{ lbs} = \$1135.92 \times 2167 = \$2,461,534$

Rounding.....466

 $\$2,462,000$

89

**Total pounds VOCs Removed per Month in A/M Area
FY 1995 and FY 1996**

| FY '95 | Oct. '94 | Nov. '94 | Dec. '94 | Jan. '95 | Feb. '95 | Mar. '95 | April '95 | May '95 | June '95 | July '95 | Aug. '95 | Sept. '95 | Total | | |
|-------------------|----------|----------|----------|----------|----------|----------|-----------|---------|---------------------------|---------------------------|----------|-----------|---------|--------------------------|-----|
| M-1 Stripper | 1719 | 1444 | 823 | 785 | 598 | 1544 | 1174 | 1174 | 608 | 783 | 0 | 1893 | 12543 | | |
| A-1 Stripper | 55 | 47 | 43 | 47 | 18 | 48 | 35 | 33 | 48 | 88 | 5 | 47 | 480 | | |
| IDU | 445 | 0 | 0 | 345 | 0 | 0 | 0 | 22 | 298 | 1178 | 3355 | 508 | 6143 | | |
| SVEU 3M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1000 | 1800 | 700 | 3000 | 3200 | 9500 | | |
| SVEU 4M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1800 | 1800 | 600 | 700 | 600 | 5300 | | |
| SVEU 5M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1900 | 1300 | 1400 | 2200 | 1800 | 8300 | | |
| SVEU 6M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1400 | 200 | 0 | 600 | 1800 | 4000 | | |
| | | | | | | | | FY '95 | Total pounds VOCs removed | | | | 48248 | 74% target 80472 | |
| FY '98 | Oct. '98 | Nov. '98 | Dec. '98 | Jan. '99 | Feb. '99 | Mar. '99 | April '99 | May '99 | June '99 | July '99 | Aug. '99 | Sept. '99 | Total | | |
| M-1 Stripper | 1200 | 1640 | 1307 | 1428 | 1156 | 702 | 1420 | | | | | | 8751 | | |
| A-1 Stripper | 43 | 43 | 40 | 28 | 7 | 6 | 48 | | | | | | 215 | | |
| IDU | 885 | 742 | 708 | 600 | 600 | 600 | 600 | | | | | | 4833 | | |
| SVEU 3M | 2200 | 1800 | 300 | 300 | 1000 | 2000 | 3100 | 1400 | | | | | 12100 | | |
| SVEU 4M | 600 | 1200 | 1000 | 1500 | 700 | 1800 | 1500 | 500 | | | | | 6800 | | |
| SVEU 5M | 1100 | 1200 | 1600 | 1600 | 700 | 1600 | 700 | 1200 | | | | | 10000 | | |
| SVEU 6M | 600 | 1400 | 2000 | 1200 | 2800 | 2200 | 1600 | 1100 | | | | | --12900 | | |
| A-2 Stripper | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | | |
| Other. | 170 | 185 | 170 | 170 | 160 | 170 | 165 | 170 | | | | | 1340 | | |
| Sum | 7098 | 8090 | 7423 | 6824 | 6923 | 9078 | 8133 | 4370 | | | | | | % of goal | |
| % of monthly goal | 105.6 | 120.6 | 110.7 | 101.6 | 103.2 | 135.4 | 138.2 | 65.2 | FY '98 | Total pounds VOCs removed | | | | 58939 | 73 |
| | | | | | | | | | | | | | | current % of annual goal | 110 |

BP and PC

06/19/96 WED 08:21 FAX 803648922

WESTINGHOUSE SAVANNAH RIVER COMPANY

INTER-OFFICE MEMORANDUM

ENGINEERING & CONSTRUCTION SERVICES
SITE PROJECT ESTIMATING DEPARTMENT

ECS-SPE-96-0327

DATE: July 25, 1996

TO: G. J. HOOKER, 773-41A / 253

FROM: R. M. SIMPSON, 730-1B / 114

BY: C.B. JORDAN, 730-1B / 1066

COMPARATIVE COST FOR THE M-1 AIR STRIPPER, VALDOSE ZONE SOIL VAPOR EXTRACTION AND IN-WELL VAPOR STRIPPING (U)

Estimate Log No: 96-06-07A and 96-07-11 Estimate Type: Comparative Cost

Attached is the capital costs and operation and maintenance cost for the above listed treatment technologies.

COST BASIS:

The cost are based on previous life cycle costs and other information supplied by the ER Group.

ASSUMPTIONS:

The costs are in FY'96 Dollars. SRS Site mark-ups for subcontract work, construction management and projectsupport are not included.

MANAGEMENT RESERVE / CONTINGENCY:

No Management reserve or Contingency is included in the costs for this study.

ESTIMATE CLOSURE:

No response is required for this study.

DDH

cc: R. M. Simpson, 730-1B / 114
J. W. Iwert, 773-41A / 251
Estimate File

PROJECT NO: N/A
 PROJ. NAME: Comparative Technology Cost
 LOG NO: 96-07-11

SITE PROJECT ESTIMATING

ESTIMATE DETAIL SHEET

ESTD BY: C. Jordan, D. Hansen
 PHONE: 3-6646
 LOG: 730-1B/1086

| ITEM | WBS | CSI | TWC | DESCRIPTION | QTY | UNIT | COST | M-HRS | CR | M-HRS | LABOR | LABOR | SHOUD | BULK | B/C | TOTAL |
|------|-----|-----|-----|---------------------------------|-----|------|-------------|-------|----|-------|-------|-------|--------|-------|-----|-----------|
| | | | | | | | | | | | RATE | | EQUIP. | MATL. | | DOLLARS |
| 1.0 | | | | M-1 Air Stripper (ADS-816/1701) | | | | | | | | | | | | |
| 1.1 | | | | Capital Cost | | | | | | | | | | | | |
| | | | | Total Capital Cost (FY90 \$) | | | \$4,552,000 | | | | | | | | | |
| | | | | (Assume 30 Yr. Life) | | | | | | | | | | | | |
| | | | | Cost Per Year | | | | | | | | | | | | \$151,700 |
| | | | | Escalation 1990 to 1996 @ | | | 13.70% | | | | | | | | | \$20,800 |
| | | | | Total Yearly Capital Cost | | | | | | | | | | | | \$172,500 |
| 1.2 | | | | Operations & Maintenance | | | | | | | | | | | | |
| | | | | M-1 Stripper - RMET Avg. Yr. | | | | | | | | | | | | \$822,500 |
| | | | | ER Labor - Exempt | | | | | | | | | | | | \$307,700 |
| | | | | ER Labor - Non-Exempt | | | | | | | | | | | | \$12,300 |
| | | | | Power & Misc. O & M Costs | | | | | | | | | | | | \$27,500 |
| | | | | Total Yearly O & M Costs | | | | | | | | | | | | \$970,000 |
| 2.0 | | | | Vadose Zone (ADS - 816/1704) | | | | | | | | | | | | |
| 2.1 | | | | Capital Cost | | | | | | | | | | | | |
| | | | | Total Capital Cost (FY95 \$) | | | \$3,610,000 | | | | | | | | | |
| | | | | (Assume 15 Yr. Life) | | | | | | | | | | | | |
| | | | | Cost Per Year | | | | | | | | | | | | \$254,000 |
| | | | | Escalation 1995 to 1996 @ | | | 2.00% | | | | | | | | | \$6,600 |
| | | | | Total Yearly Capital Cost | | | | | | | | | | | | \$260,600 |
| 2.2 | | | | Operations & Maintenance | | | | | | | | | | | | |
| | | | | Vadose Zone - RMET - F | | | | | | | | | | | | \$501,000 |
| | | | | ER Labor - Exempt | | | | | | | | | | | | \$391,000 |
| | | | | ER Labor - Non-Exempt | | | | | | | | | | | | \$48,000 |
| | | | | Power & Misc. O & M Costs | | | | | | | | | | | | \$25,000 |
| | | | | Total Yearly O & M Costs | | | | | | | | | | | | \$964,000 |

PROJECT NO : N/A
 PROJ NAME : Comparative Technology Cost
 LOG NO : 88-07-11

SITE PROJECT ESTIMATING

ESTIMATE DETAIL SHEET

ESTD BY : C. Jordan, D. Hansen
 PHONE : 8-8340
 LOG : 730-18/1066

| ITEM | WBS | CSI | TWC | DESCRIPTION | QTY | UNIT | UNIT COST | AMT | AMT | LABOR RATE | LABOR | ENGND EQUIP. | BULK MATL | B/C | TOTAL DOLLARS |
|------|-----|-----|-----|---|-----|------|-------------|-----|-----|------------|-------|--------------|-----------|-----|---------------|
| 3.0 | | | | Southern Sector In-Well Vapor Stripping | | | | | | | | | | | |
| 3.1 | | | | Capital Cost | | | | | | | | | | | |
| | | | | Total Capital Cost (FY'96 \$) | | | \$1,873,000 | | | | | | | | |
| | | | | (Assume 30 Yr. Life) | | | | | | | | | | | |
| | | | | Cost Per Year | | | | | | | | | | | \$62,400 |
| | | | | Total Yearly Capital Cost | | | | | | | | | | | \$62,400 |
| 3.2 | | | | Operations & Maintenance | | | | | | | | | | | |
| | | | | ER Labor | | | | | | | | | | | \$41,000 |
| | | | | Inspection & Maintenance | | | | | | | | | | | \$47,000 |
| | | | | Power & Misc. O & M Costs | | | | | | | | | | | \$12,000 |
| | | | | Total Yearly O & M Costs | | | | | | | | | | | \$100,000 |

07/23/96 TUE 12:46 FAX 8037234129

ID Program Office

EXHIBIT V
(2 pages)

0002

M-1 AIR STRIPPER - CAPITAL COST

Savannah River - Page 8 of 12

COST

• The production air stripper was designed and constructed in 1984-1985. The major capital cost elements associated are provided below. Annual operating costs based upon data from 1985 through 1990 are also listed. All information is based on an analysis performed in 1990 and all costs are in 1990 dollars.

• During 1985 to 1990, the average volume of water treated by the air stripper was 198 million gallons per year. Using the operating costs detailed below (in 1990 dollars), the total cost of operation and maintenance is \$0.76 per 1000 gallons treated.

• An assessment of total cost and duration of operation for the pump and treat system to complete the cleanup is not possible due to the multi-phased approach to environmental restoration of the AML Area. As detailed on page 8, the overall treatment plan for the site includes future identification and implementation of technologies to achieve cleanup goals. The extent to which the pump and treat system will be part of that effort has not yet been determined therefore projected costs to cleanup can not be estimated.

Capital Costs

| | |
|--|-----------|
| Design | \$428,000 |
| Contracts (purchasing, modeling, etc.) | 368,000 |
| Site Development | 28,000 |
| QA Engineering | 18,000 |
| Control Building | 211,000 |
| Electrical | 877,000 |
| Instrumentation | 468,000 |
| Piping/Construction | 925,000 |
| Tower Installation | 132,000 |
| Control System | 238,000 |
| Erect/Test Tower | 428,000 |

Total \$4,103,000

Operating Costs

| | |
|--------------------------------|----------|
| Electrical Power (\$0.052/kwh) | \$26,000 |
| Maintenance | |
| Labor (\$9.52/hr) | 13,500 |
| Equipment repair & replacement | 13,000 |
| Operation | |
| Operation & daily inspections | 45,700 |
| Well sampling & lab analysis | 15,000 |
| Engineering support | 36,000 |

Total Annual Operating Cost \$148,200

Escalate to '96



U.S. Department of Energy

Savannah River - Page 11 of 12 -

ANALYSIS PREPARATION

This analysis was prepared by:
**Stone & Webster Environmental
Technology & Services**



345 Summer Street
Boston, MA 02210
Contact: Bruno Brodfield (617) 549-2767

Assistance was provided by the
WESTINGHOUSE SAVANNAH RIVER COMPANY
which supplied key information and reviewed report drafts.

for:



HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
Environmental Restoration and Waste Management Programs
Oak Ridge, Tennessee 37831-7608

managed by
MARTIN MARSHALL ENERGY SYSTEMS
for the

U.S. Department of Energy
under Contract DE-AC05-84OR-21400

This analysis was funded by:



U.S. Air Force
Headquarters USAFCEVR

CERTIFICATION

This analysis accurately reflects the performance and costs of the remediation:

[Signature]
C.L. Bergen

Westinghouse Savannah River Company
Environmental Restoration Department
Manager Northern Ground Water Facilities

[Signature]
G.E. Turner

Department of Energy
Savannah River Operations Office
Environmental Restoration Division
Environmental Specialist



U.S. Department of Energy

January 31, 1996

400349

EXHIBIT VII
DATA FOR ESTIMATING COST SAVINGS OF VERTICAL RECIRCULATION WELLS
 (Provided by Roger White, 7/16/96)

| | | |
|-----|---|-----------|
| 1. | Install 12(8" dia) wells: 12x170' = 2040 linear feet estimate \$17,000 per well | \$204,000 |
| 2. | Air Compressor, 30hp 12x\$25,000 ea | \$300,000 |
| 3. | Equipment enclosures: 12x\$10,000 | \$120,000 |
| 4. | Vacuum System, 10hp 12x\$10,000 | \$120,000 |
| 5. | Electrical Utilities: Run 13.8 etc. | \$300,000 |
| 6. | Finishing Materials for Wells 12x\$4000 | \$48,000 |
| 7. | Well Packers 12x\$8000 | \$96,000 |
| 8. | PVC Casing & Screens 12x\$5000 | \$60,000 |
| 9. | Monitoring Wells, 8: 8x\$1200 | \$96,000 |
| 10. | Characterization 12x\$4000 | \$48,000 |
| 11. | Installation for above ground components: | \$50,000 |
| 12. | O&M Cost: Energy...assume 20hp continuous Inspection: 2 hrs per day Maintenance: \$10,000 per year ER Exempt Labor: 1/4 FTE | |
| 13. | Productivity of wells: 0.0217 lbs solvent per hour per well [This to be documented in formal calculation by SRTC] Estimated solvent concentration in Southern Sector groundwater is 500 parts per billion. | |
| 14. | License fees to EG&G for use of patents | \$128,000 |
| 15. | M-1 Stripper Feedstream: (per Michael Hartz) Solvent concentration (1995 annual average): TCE 4.1ppm PCE 2.9ppm Total 7.0ppm | |

EXHIBIT VIII
(Misc. Notes)

M-1 Air Strapper (1706)

OPERATIONS

FY96

Capital Cost

| | |
|----------------|----------|
| Total Op. Cost | 4103.000 |
|----------------|----------|

OFF GAS SYS. 449 000

| | |
|-----|-----------|
| S/T | A4552.000 |
|-----|-----------|

| | |
|-------------|-----------|
| PER YA COST | \$151,733 |
|-------------|-----------|

Escrow '90-'96

FY XX-(AY6-7499)

622,506

RAET

50% ER LABOR EXEMPT.

307,655

EXHIBIT

SDJ. 11 " New Exam

12295

No Entry

Subtopic

942,456

Elect, Co + Mt

26000

Process Mods

965,452

\$154K

2952

449

M-1 DEFENSE TRNG. SYS.

| | |
|--|--------------|
| VADOSE ZONE (1704) - ESCALATE CAPTION 95 to 96 | |
| CAPITAL COST - ? | \$3810,000 + |
| PER YR COST @ 15% YR | 254,000 / YR |
| OPERATIONS - | |
| VADOSE ZONE - R/MET-F | 501,000 |
| ER LAGOON - EXEMPT | 591,000 |
| ER LAGOON - NON EXEMPT | 46,000 |
| SUBTOTAL OPERATIONS | 938,000 |
| ELECT, MNT & LOG | 26,000 |
| | 964,000 |

SOUTHERN SECTOR (1703) - IN WELL VAPOR STRIPPING
12 WELLS

| | |
|-----------------------------|----------------------------|
| DESIGN | 100,000 |
| WELL INSTALL, EQUIP / Pwr | 1,453,000 |
| SITING AND POC | 150,000 |
| MISC - PERMITS, OTHER SUPPL | 170,000 |
| | 1,873,000 ÷ 30 YR = 62,400 |

O & M

| | |
|--------------------|---------|
| PWR | 12,000 |
| INSPECTION & MAINT | 47,000 |
| ER LAGOON 500 MHR | 41,000 |
| | 100,000 |

Pr1 26 Jan 1996

U.S. Department of Energy
PROJECT 16706T: A-1/N-1 AIR STRIPPER GU - ADS 516, REVISION FY96.02
A-1/N-1 AIR STRIPPER GROUNDWATER
** PROJECT DIRECT SUMMARY - LEVEL 3 **

TIME 15:14:06

SUMMARY PAGE 7

| | QUANTITY UOM | LABOR | EQUIPMENT | MAT/SUPP | UNIT COST | TOTAL COST | UNIT COST |
|-------------------------------------|-------------------------------------|-----------|-----------|----------|------------|------------|-----------|
| A GROUNDWATER ASSESSMENT | | | | | | | |
| A.08 ADDITIONAL STUDIES | | | | | | | |
| A.08.02 | A-1 SYS. CYCLING DEMO S/C FY97 | 67.00 HR | 5,377 | 0 | 0 | 5,377 | 80.25 |
| A.08.04 | A-1 SYS. CYCLING DEMO ERIC FY97 | 150.00 HR | 12,038 | 0 | 0 | 12,038 | 80.25 |
| A.08.06 | DEVELOP PROCEDURE - S/C FY97 | 67.00 HR | 5,377 | 0 | 0 | 5,377 | 80.25 |
| ADDITIONAL STUDIES | | | 22,791 | 0 | 0 | 22,791 | |
| A.09 REGULATORY REQUIREMENTS | | | | | | | |
| A.09.02 | INTROD AIR PERM MOD SC FY99 | 0 | 0 | 0 | 21,400 | 21,400 | |
| A.09.03 | INTROD AIR PERM MOD SC FY00-22 | 0 | 0 | 0 | 470,800 | 470,800 | |
| A.09.04 | A-1A CUTFLL NPDES RENEAL SC FY99 | 0 | 0 | 0 | 32,100 | 32,100 | |
| A.09.05 | A-1A CUTFLL NPDES RENEAL SC FY00-22 | 0 | 0 | 0 | 706,200 | 706,200 | |
| A.09.06 | A-1 AIR PERMIT RENEAL SC FY99 | 0 | 0 | 0 | 21,400 | 21,400 | |
| A.09.07 | A-1 AIR PERMIT RENEAL SC FY00-22 | 0 | 0 | 0 | 470,800 | 470,800 | |
| A.09.08 | M-1 AIR PERMIT RENEAL SC FY97 | 0 | 0 | 0 | 32,100 | 32,100 | |
| A.09.16 | M-1 AIR PERMIT RENEAL SC FY99 | 0 | 0 | 0 | 21,400 | 21,400 | |
| A.09.18 | M-1 AIR PERMIT RENEAL SC FY00-22 | 0 | 0 | 0 | 470,800 | 470,800 | |
| A.09.21 | VADOSE ZONE RENEAL FY99 | 0 | 0 | 0 | 64,200 | 64,200 | |
| A.09.22 | VADOSE ZONE RENEAL FY00-22 | 0 | 0 | 0 | 256,800 | 256,800 | |
| REGULATORY REQUIREMENTS | | 0 | 0 | 0 | 2,568,000 | 2,568,000 | |
| A.95 AOP - FISCAL YEAR 1995 | | | | | | | |
| A.95.01 | AOP - FISCAL YEAR 1995 | | 635,688 | 0 | 1,439,150 | 2,074,838 | |
| AOP - FISCAL YEAR 1995 | | | 635,688 | 0 | 1,439,150 | 2,074,838 | |
| GROUNDWATER ASSESSMENT | | | 658,479 | 0 | 4,007,150 | 4,665,629 | |
| O GROUNDWATER OPERATIONS | | | | | | | |
| O.14 OPERATIONS | | | | | | | |
| O.14.02 | M-1 STRIPPER - RHET FY96 | 47,000 | 0 | 42,800 | 559,931 | 649,731 | |
| O.14.04 | M-1 STRIPPER - RHET FY97 | 0 | 0 | 0 | 565,281 | 565,281 | |
| O.14.06 | M-1 STRIPPER - RHET FY98 | 0 | 0 | 0 | 629,481 | 629,481 | |
| O.14.08 | M-1 STRIPPER - RHET FY99 | 0 | 0 | 0 | 645,531 | 645,531 | |
| O.14.10 | M-1 STRIPPER - RHET FY00 - 22 | 23.00 YR | 0 | 0 | 15,413,243 | 15,413,243 | |
| O.14.14 | A-1 STRIPPER - RHET FY96 | 23,000 | 0 | 21,400 | 418,370 | 422,970 | |
| O.14.16 | A-1 STRIPPER - RHET FY97 | 0 | 0 | 0 | 365,405 | 365,405 | |
| O.14.18 | A-1 STRIPPER - RHET FY98 | 0 | 0 | 0 | 409,275 | 409,275 | |
| O.14.20 | A-1 STRIPPER - RHET FY99 | 0 | 0 | 0 | 419,975 | 419,975 | |

WISRC-TR-97-00283
September 19, 1997
Rev. 0
Page C-18

400354

Fri 26 Jan 1996

U.S. Department of Energy
 PROJECT 16706T: A-1/M-1 AIR STRIPPER GW - ADD 516, REVISION FY96.02
 A-1/M-1 AIR STRIPPER GROUNDWATER
 ** PROJECT DIRECT SUMMARY - LEVEL 3 **

TIME 15:14:06

SUMMARY PAGE 8

| | QUANTITY UOM | LABOR | EQUIPMENT | MAT/SUPP | UNIT COST | TOTAL COST | UNIT COST |
|--------------------------------------|--------------|------------|-----------|----------|------------|------------|-----------|
| 0.14.22 A-1 STRIPPER -RMET FY00-22 | 23.00 YR | 0 | 0 | 0 | 10,028,375 | 10,028,375 | 436025.00 |
| 0.14.26 LABOR FY96 | | 880,134 | 0 | 0 | 0 | 880,134 | |
| 0.14.26 ER LABOR EXEMPT FY97 | 7461.00 HR | 615,309 | 0 | 0 | 0 | 615,309 | 82.47 |
| 0.14.28 ER LABOR EXEMPT FY98 | 7461.00 HR | 615,309 | 0 | 0 | 0 | 615,309 | 82.47 |
| 0.14.30 ER LABOR EXEMPT FY99 | 7461.00 HR | 615,309 | 0 | 0 | 0 | 615,309 | 82.47 |
| 0.14.32 ER LABOR EXEMPT FY00 - 22 | 171603.00 HR | 14,152,099 | 0 | 0 | 0 | 14,152,099 | 82.47 |
| 0.14.34 ER LABOR NONEXEMPT FY96 | 487.00 HR | 24,589 | 0 | 0 | 0 | 24,589 | 50.49 |
| 0.14.36 ER LABOR NONEXEMPT FY98 | 487.00 HR | 24,589 | 0 | 0 | 0 | 24,589 | 50.49 |
| 0.14.38 ER LABOR NONEXEMPT FY99 | 487.00 HR | 24,589 | 0 | 0 | 0 | 24,589 | 50.49 |
| 0.14.40 ER LABOR NONEXEMPT FY00-22 | 11201.00 HR | 565,538 | 0 | 0 | 0 | 565,538 | 50.49 |
| 0.14.51 PROCESS MODIFICATIONS | | 133,849 | 0 | 0 | 0 | 133,849 | |
| 0.14.55 M-1 OFF-GAS TREATMENT SYSTEM | | 144,907 | 5,350 | 75,669 | 69,336 | 295,262 | |
| OPERATIONS | | 17,886,219 | 5,350 | 139,869 | 29,324,403 | 47,555,841 | |
| GROUNDWATER OPERATIONS | | 17,886,219 | 5,350 | 139,869 | 29,324,403 | 47,555,841 | |
| A-1/M-1 AIR STRIPPER GW | | 18,944,698 | 5,350 | 139,869 | 33,331,553 | 52,221,470 | |

Fri 26 Jan 1996

U.S. Department of Energy
PROJECT 167040: VADOSE ZONE GV OPERATIONS - ADS 516, REVISION FY96.02
VADOSE ZONE GROUNDWATER
** PROJECT OWNER SUMMARY - LEVEL 3 **

TIME 15:13:35
SUMMARY PAGE 3

| | QUANTITY UN | CONTRACT COST | RZ/HR | CAS | CH | PH/PC | TOTAL COST | UNIT COST |
|--|--------------|---------------|-------|-----|----|-------|------------|-----------|
| C GROUNDWATER CLOSURE | | | | | | | | |
| C.95 AOP - FISCAL YEAR 1995 | | | | | | | | |
| C.95.01 AOP - FISCAL YEAR 1995 | | 119,908 | 0 | 0 | 0 | 0 | 119,908 | |
| AOP - FISCAL YEAR 1995 | | 119,908 | 0 | 0 | 0 | 0 | 119,908 | |
| GROUNDWATER CLOSURE | | 119,908 | 0 | 0 | 0 | 0 | 119,908 | |
| D GROUNDWATER OPERATIONS | | | | | | | | |
| D.14 OPERATIONS | | | | | | | | |
| 0.14.02 VADOSE ZONE (N-AREA) - RNET F | | 459,512 | 0 | 0 | 0 | 0 | 459,512 | |
| 0.14.04 VADOSE ZONE (N-AREA) - RNET F | | 475,562 | 0 | 0 | 0 | 0 | 475,562 | |
| 0.14.06 VADOSE ZONE (N-AREA) - RNET F | | 527,992 | 0 | 0 | 0 | 0 | 527,992 | |
| 0.14.08 VADOSE ZONE (N-AREA) - RNET F | | 540,832 | 0 | 0 | 0 | 0 | 540,832 | |
| 0.14.20 VADOSE ZONE (N-AREA) RNET FY00 | 23.00 YR | 12,906,715 | 0 | 0 | 0 | 0 | 12,906,715 | 561161.50 |
| 0.14.22 ER LABOR EXEMPT FY96 | 4740.00 HR | 390,908 | 0 | 0 | 0 | 0 | 390,908 | 82.47 |
| 0.14.24 ER LABOR EXEMPT FY97 | 4740.00 HR | 390,908 | 0 | 0 | 0 | 0 | 390,908 | 82.47 |
| 0.14.26 ER LABOR EXEMPT FY98 | 4740.00 HR | 390,908 | 0 | 0 | 0 | 0 | 390,908 | 82.47 |
| 0.14.28 ER LABOR EXEMPT FY99 | 4740.00 HR | 390,908 | 0 | 0 | 0 | 0 | 390,908 | 82.47 |
| 0.14.30 ER LABOR EXEMPT FY00 - 22 | 109020.00 HR | 8,990,879 | 0 | 0 | 0 | 0 | 8,990,879 | 82.47 |
| 0.14.32 ER LABOR NONEXEMPT FY96 | 910.00 HR | 45,946 | 0 | 0 | 0 | 0 | 45,946 | 50.49 |
| 0.14.34 ER LABOR NONEXEMPT FY97 | 910.00 HR | 45,946 | 0 | 0 | 0 | 0 | 45,946 | 50.49 |
| 0.14.36 ER LABOR NONEXEMPT FY98 | 910.00 HR | 45,946 | 0 | 0 | 0 | 0 | 45,946 | 50.49 |
| 0.14.38 ER LABOR NONEXEMPT FY99 | 910.00 HR | 45,946 | 0 | 0 | 0 | 0 | 45,946 | 50.49 |
| 0.14.40 ER LABOR NONEXEMPT FY00 - 22 | 20930.00 HR | 1,056,756 | 0 | 0 | 0 | 0 | 1,056,756 | 50.49 |
| OPERATIONS | | 26,705,660 | 0 | 0 | 0 | 0 | 26,705,660 | |
| GROUNDWATER OPERATIONS | | 26,705,660 | 0 | 0 | 0 | 0 | 26,705,660 | |
| VADOSE ZONE GV OPERATIONS | | 26,825,568 | 0 | 0 | 0 | 0 | 26,825,568 | |

Avg.
509975

WSRC-TR-97-00283
September 19, 1997
Rev. 0
Page C-20

400356

Equation for Calculating Unit Cost for In Situ Oxidation Technology

Unit Cost = (Mobilization/Setup + Pre-test Characterization + Treatment System Operation + Peroxide + Demobilization + Document Preparation + Post-test Characterization + Project Management)/Pound of DNAPL

Unit Cost = [mobilization and setup + (pre-test drilling + pre-test analysis + pre-test oversight) + (operation oversight + operation) + peroxide + demobilization + document preparation + (post-test drilling + post-test analysis + post-test oversight)]/pound of DNAPL

Total Cost = \$60,000 + ((\$70 per ft pre-test * ft pre-test) + (\$15 per ft pre-test * ft pre-test) + (\$2,800 per day pre-test * days of drilling pre-test)) + ((\$2,500 per day * days operation) + (\$15,000 per day * days operation)) + (\$21 per pound DNAPL * pounds DNAPL) + \$10,000 + \$40,000 + ((\$47 per ft post-test * ft post-test) + (\$15 per ft post-test * ft post-test) + (\$2,800 per day post-test * days of drilling post-test)) + 0.05 * Total Cost

Total Cost = [(\$60,000 + \$10,000 + \$40,000) + ((\$70 per ft pre-test + \$15 per ft pre-test) * 0.73 * total footage drilled) + (\$2,800 per day * (days of pre-test drilling + days of post-test drilling)) + (\$17,500 per day * days operation) + (\$21 per pound DNAPL * pounds DNAPL) + ((\$47 per ft post-test + \$15 per ft post-test) * 0.27 * total footage drilled)]/0.95

Total Cost = [\$110,000 + ((((\$85 * 0.73) + (\$62 * 0.27)) * total footage drilled) + (\$2,800 * total days drilling) + (\$17,500 * days operation) + (\$21 per pound DNAPL * pounds DNAPL)]/0.95

Total Cost = [\$110,000 + (\$78.8 * total footage drilled) + (\$2,800 * total days drilling) + (\$17,500 * days operation) + (\$21 per pound DNAPL * pounds DNAPL)]/0.95

Unit Cost = Total Cost/pound of DNAPL

Calculation of Unit Cost based on a \$/ft³ of soil treated.

This was calculated based on the amount of DNAPL required at depth X where an approximate cost of \$87/pound of DNAPL treated was determined (See Table 10.3).

The volume of soil to be treated is 64,000 pounds (based on size of demonstration site)

For example: at 60 ft depth, 6,750 pounds of DNAPL is needed to yield a \$84/pound of DNAPL treated cost.

Unit Cost (\$/ft³) = Unit Cost (\$/pound DNAPL) * pounds of DNAPL/Volume of soil treated

Unit Cost (\$/ft³) = \$84/pound DNAPL * 6750 pounds DNAPL/64,000 ft³ of soil

Unit Cost (\$/ft³) = \$8.84/ft³

400358

APPENDIX E
NASSAU COUNTY GROUNDWATER DATA

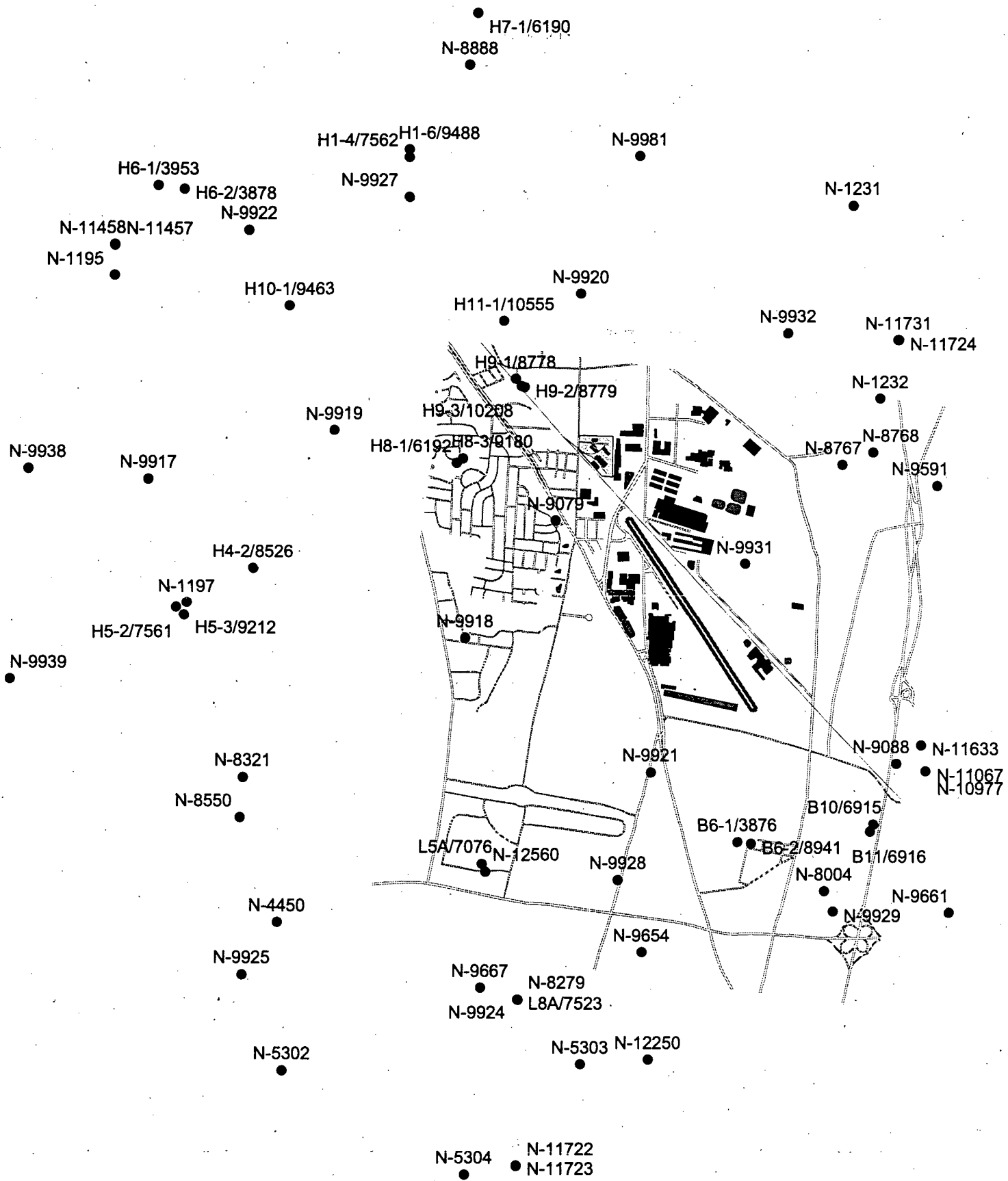
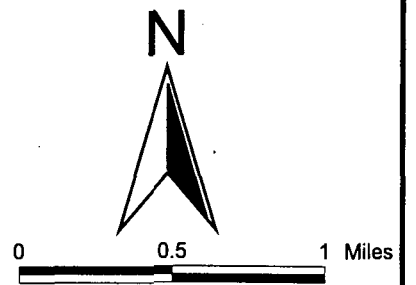


Figure 1
COUNTY WELLS
Hicksville, New York

- County Wells
- ▬ Runway
- ▬ Roads
- ▬ Railroad
- Building
- ▨ Ruco Boundary
- Basin

CRA

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| B10/6915 | 13-Jan-97 | 0.5 U | 0.5 U | 0.5 U |
| B10/6915 | 05-Feb-97 | 1.8 | 7.8 | 0.5 U |
| B10/6915 | 05-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| B10/6915 | 07-Apr-97 | 0.5 U | 0.9 | 0.5 U |
| B10/6915 | 20-May-97 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 03-Jun-97 | 0.5 U | 1.1 | 0.5 U |
| B10/6915 | 08-Jul-97 | 0.5 U | 0.9 | 0.5 U |
| B10/6915 | 05-Aug-97 | 0.5 U | 1 | 0.5 U |
| B10/6915 | 04-Sep-97 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 09-Oct-97 | 0.5 U | 0.7 | 0.5 U |
| B10/6915 | 25-Nov-97 | 0.5 U | 0.5 U | 0.5 U |
| B10/6915 | 03-Dec-97 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 13-Jan-98 | 0.5 U | 1.2 | 0.5 U |
| B10/6915 | 10-Feb-98 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 03-Mar-98 | 0.5 U | 0.6 | 0.5 U |
| B10/6915 | 07-Apr-98 | 0.5 U | 0.6 | 0.5 U |
| B10/6915 | 12-May-98 | 0.5 U | 0.9 | 0.5 U |
| B10/6915 | 04-Jun-98 | 0.5 U | 0.6 | 0.5 U |
| B10/6915 | 08-Jul-98 | 0.5 U | 1 | 0.5 U |
| B10/6915 | 04-Aug-98 | 0.5 U | 0.7 | 0.5 U |
| B10/6915 | 03-Sep-98 | 0.5 U | 1 | 0.5 U |
| B10/6915 | 01-Oct-98 | 0.5 U | 1.7 | 0.5 U |
| B10/6915 | 23-Nov-98 | 0.5 U | 0.7 | 0.5 U |
| B10/6915 | 02-Dec-98 | 0.5 U | 0.5 U | 0.5 U |
| B10/6915 | 05-Jan-99 | 0.5 U | 0.5 U | 0.5 U |
| B10/6915 | 18-Feb-99 | 0.5 U | 0.6 | 0.5 U |
| B10/6915 | 16-Mar-99 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 29-Apr-99 | 0.5 U | 0.7 | 0.5 U |
| B10/6915 | 19-May-99 | 0.5 U | 0.5 | 0.5 U |
| B10/6915 | 17-Jun-99 | 0.5 U | 0.8 | 0.5 U |
| B10/6915 | 19-Jul-99 | 0.5 U | 1.2 | 0.5 U |
| B11/6916 | 13-Jan-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 05-Feb-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 05-Mar-97 | 0.5 U | 1.1 | 0.5 U |
| B11/6916 | 07-Apr-97 | 0.5 U | 0.7 | 0.5 U |
| B11/6916 | 20-May-97 | 0.5 U | 1.9 | 0.5 U |
| B11/6916 | 03-Jun-97 | 0.5 U | 0.5 | 0.5 U |
| B11/6916 | 08-Jul-97 | 0.5 U | 0.7 | 0.5 U |
| B11/6916 | 05-Aug-97 | 0.5 U | 0.8 | 0.5 U |
| B11/6916 | 04-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 09-Oct-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 25-Nov-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 03-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 13-Jan-98 | 0.5 U | 0.6 | 0.5 U |
| B11/6916 | 10-Feb-98 | 0.5 U | 0.6 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|---------------------|---|---------------------------------------|--------------------------------------|
| B11/6916 | 03-Mar-98 | 0.5 U | 0.6 | 0.5 U |
| B11/6916 | 07-Apr-98 | 0.5 U | 0.7 | 0.5 U |
| B11/6916 | 12-May-98 | 0.5 U | 0.8 | 0.5 U |
| B11/6916 | 04-Jun-98 | 0.5 U | 0.8 | 0.5 U |
| B11/6916 | 08-Jul-98 | 0.5 U | 1.1 | 0.5 U |
| B11/6916 | 04-Aug-98 | 0.5 U | 1.1 | 0.5 U |
| B11/6916 | 03-Sep-98 | 0.5 U | 1.3 | 0.5 U |
| B11/6916 | 01-Oct-98 | 0.5 U | 1.7 | 0.5 U |
| B11/6916 | 23-Nov-98 | 0.5 U | 1.4 | 0.5 U |
| B11/6916 | 02-Dec-98 | 0.5 U | 1.2 | 0.5 U |
| B11/6916 | 05-Jan-99 | 0.5 U | 1.6 | 0.5 U |
| B11/6916 | 18-Feb-99 | 0.5 U | 0.5 U | 0.5 U |
| B11/6916 | 16-Mar-99 | 0.5 U | 1.3 | 0.5 U |
| B11/6916 | 30-Apr-99 | 0.5 U | 1.1 | 0.5 U |
| B11/6916 | 20-May-99 | 0.5 U | 0.6 | 0.5 U |
| B11/6916 | 17-Jun-99 | 0.5 U | 0.6 | 0.5 U |
| B11/6916 | 19-Jul-99 | 0.5 U | 1.1 | 0.5 U |
| B6-1/3876 | 16-Apr-97 | 10 | 260 | 0.5 U |
| B6-1/3876 | 16-Apr-97 duplicate | 12 | 240 | |
| B6-1/3876 | 20-May-97 | 8.8 | 260 | 0.5 U |
| B6-1/3876 | 30-Jun-97 | 11 | 360 | 0.5 U |
| B6-1/3876 | 08-Jul-97 | 7.1 | 310 | 0.5 U |
| B6-1/3876 | 05-Aug-97 | 6.9 | 200 | 0.5 U |
| B6-1/3876 | 04-Sep-97 | 8.9 | 260 | 0.5 U |
| B6-1/3876 | 09-Oct-97 | 7.2 | 290 | 0.5 U |
| B6-1/3876 | 25-Nov-97 | 5.8 | 200 | 0.5 U |
| B6-1/3876 | 03-Dec-97 | 6.4 | 210 | 0.5 U |
| B6-1/3876 | 13-Jan-98 | 5.3 | 190 | 0.5 U |
| B6-1/3876 | 10-Feb-98 | 4.7 | 170 | 0.5 U |
| B6-1/3876 | 03-Mar-98 | 5.7 | 200 | 0.5 U |
| B6-1/3876 | 07-Apr-98 | 7.1 | 200 | 0.5 U |
| B6-1/3876 | 12-May-98 | 8.2 | 250 | 0.5 U |
| B6-1/3876 | 04-Jun-98 | 8.7 | 270 | 0.5 U |
| B6-1/3876 | 08-Jul-98 | 11 | 210 | 0.5 U |
| B6-1/3876 | 04-Aug-98 | 7.1 | 210 | 0.5 U |
| B6-1/3876 | 03-Sep-98 | 6.8 | 200 | 0.5 U |
| B6-1/3876 | 01-Oct-98 | 6.6 | 190 | 0.5 U |
| B6-1/3876 | 23-Nov-98 | 6.4 | 190 | 0.5 U |
| B6-1/3876 | 02-Dec-98 | 5.8 | 160 | 0.5 U |
| B6-1/3876 | 05-Jan-99 | 6.6 | 220 | 0.5 U |
| B6-1/3876 | 18-Feb-99 | 5.4 | 160 | 0.5 U |
| B6-1/3876 | 16-Mar-99 | 6 | 190 | 0.5 U |
| B6-1/3876 | 30-Apr-99 | 6 | 170 | 0.5 U |
| B6-1/3876 | 20-May-99 | 6.1 | 150 | 0.5 U |
| B6-1/3876 | 18-Jun-99 | 5.9 | 120 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| B6-1/3876 | 20-Jul-99 | 3 | 81 | 0.5 U |
| B6-2/8941 | 16-Apr-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 20-May-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 03-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 08-Jul-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 05-Aug-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 04-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 09-Oct-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 30-Oct-97 | 0.5 U | 0.5 U | |
| B6-2/8941 | 25-Nov-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 03-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 16-Apr-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 12-May-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 04-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 08-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 04-Aug-98 | 0.5 U | 1.8 | 0.5 U |
| B6-2/8941 | 03-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 01-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 21-Oct-98 | 13 | 200 | 0.5 U |
| B6-2/8941 | 23-Nov-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 02-Dec-98 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 05-Jan-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 18-Feb-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 16-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 29-Apr-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 20-May-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 18-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| B6-2/8941 | 20-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 19-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 05-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 17-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 11-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 16-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 17-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 22-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 15-Dec-98 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 19-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| H10-1/9463 | 11-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 19-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 05-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 17-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 15-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 16-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 17-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H11-1/10555 | 15-Dec-98 | 0.5 U | 0.5 U | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene µg/L</i> | <i>Trichloroethene µg/L</i> | <i>Vinyl Chloride µg/L</i> |
|-----------------|---------------------|-----------------------------------|---------------------------------|--------------------------------|
| H11-1/10555 | 19-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| H1-4/7562 | 22-Jan-97 | 0.7 | 1.2 | 0.5 U |
| H1-4/7562 | 27-Feb-97 | 1.4 | 4.2 | 0.5 U |
| H1-4/7562 | 24-Mar-97 | 1.8 | 4.4 | 0.5 U |
| H1-4/7562 | 24-Apr-97 | 0.7 | 1.3 | 0.5 U |
| H1-4/7562 | 29-May-97 | 1.5 | 4.6 | 0.5 U |
| H1-4/7562 | 27-Jun-97 | 1.1 | 4 | 0.5 U |
| H1-4/7562 | 29-Jul-97 | 1.3 | 3.6 | 0.5 U |
| H1-4/7562 | 26-Aug-97 | 1.5 | 4.4 | 0.5 U |
| H1-4/7562 | 23-Sep-97 | 1.4 | 4.3 | 0.5 U |
| H1-4/7562 | 28-Oct-97 | 1.4 | 4.8 | 0.5 U |
| H1-4/7562 | 25-Nov-97 | 0.5 U | 0.5 U | 0.5 U |
| H1-4/7562 | 19-Dec-97 | 0.5 U | 14 | 0.5 U |
| H1-4/7562 | 29-Jan-98 | 1.2 | 3.9 | 0.5 U |
| H1-4/7562 | 26-Feb-98 | 1.2 | 4.2 | 0.5 U |
| H1-4/7562 | 24-Mar-98 | 1.5 | 4 | 0.5 U |
| H1-4/7562 | 29-Apr-98 | 1.6 | 4.7 | 0.5 U |
| H1-4/7562 | 29-May-98 | 0.5 U | 0.5 U | 0.5 U |
| H1-4/7562 | 24-Jun-98 | 2 | 5.1 | 0.5 U |
| H1-4/7562 | 30-Jul-98 | 1.7 | 3.9 | 0.5 U |
| H1-4/7562 | 28-Aug-98 | 2 | 5.1 | 0.5 U |
| H1-4/7562 | 28-Aug-98 duplicate | 3 | 6 | |
| H1-4/7562 | 28-Sep-98 | 1.9 | 4.9 | 0.5 U |
| H1-4/7562 | 27-Oct-98 | 2.3 | 2.6 | 0.5 U |
| H1-4/7562 | 23-Nov-98 | 1.9 | 2.8 | 0.5 U |
| H1-4/7562 | 22-Dec-98 | 1.6 | 2.1 | 0.5 U |
| H1-4/7562 | 28-Jan-99 | 1.7 | 2.7 | 0.5 U |
| H1-4/7562 | 25-Feb-99 | 1.6 | 2.4 | 0.5 U |
| H1-4/7562 | 26-Mar-99 | 1.8 | 3 | 0.5 U |
| H1-4/7562 | 29-Apr-99 | 2.1 | 2.4 | 0.5 U |
| H1-4/7562 | 27-May-99 | 2.6 | 1.5 | 0.5 U |
| H1-4/7562 | 24-Jun-99 | 2.9 | 40 | 0.5 U |
| H1-4/7562 | 29-Jul-99 | 2 | 4.8 | 0.5 U |
| H1-6/9488 | 22-Jan-97 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 27-Feb-97 | 0.5 U | 17 | 0.5 U |
| H1-6/9488 | 24-Mar-97 | 0.5 U | 19 | 0.5 U |
| H1-6/9488 | 24-Apr-97 | 0.5 U | 13 | 0.5 U |
| H1-6/9488 | 29-May-97 | 0.5 U | 18 | 0.5 U |
| H1-6/9488 | 27-Jun-97 | 0.5 U | 15 | 0.5 U |
| H1-6/9488 | 29-Jul-97 | 0.5 U | 16 | 0.5 U |
| H1-6/9488 | 26-Aug-97 | 0.5 U | 17 | 0.5 U |
| H1-6/9488 | 23-Sep-97 | 0.5 U | 16 | 0.5 U |
| H1-6/9488 | 28-Oct-97 | 0.5 U | 7.3 | 0.5 U |
| H1-6/9488 | 25-Nov-97 | 0.5 U | 15 | 0.5 U |
| H1-6/9488 | 19-Dec-97 | 1.3 | 4.1 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene µg/L</i> | <i>Trichloroethene µg/L</i> | <i>Vinyl Chloride µg/L</i> |
|-----------------|---------------------|-----------------------------------|---------------------------------|--------------------------------|
| H1-6/9488 | 29-Jan-98 | 0.5 U | 13 | 0.5 U |
| H1-6/9488 | 26-Feb-98 | 0.5 U | 14 | 0.5 U |
| H1-6/9488 | 24-Mar-98 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 29-Apr-98 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 29-May-98 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 24-Jun-98 | 0.5 U | 13 | 0.5 U |
| H1-6/9488 | 30-Jul-98 | 0.5 U | 13 | 0.5 U |
| H1-6/9488 | 28-Aug-98 | 0.6 | 15 | 0.5 U |
| H1-6/9488 | 28-Aug-98 duplicate | 0.5 U | 13 | |
| H1-6/9488 | 03-Sep-98 | 0.8 | 16 | 0.5 U |
| H1-6/9488 | 28-Sep-98 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 27-Oct-98 | 0.5 U | 11 | 0.5 U |
| H1-6/9488 | 23-Nov-98 | 0.5 U | 11 | 0.5 U |
| H1-6/9488 | 22-Dec-98 | 0.5 U | 9.3 | 0.5 U |
| H1-6/9488 | 28-Jan-99 | 0.5 U | 12 | 0.5 U |
| H1-6/9488 | 25-Feb-99 | 0.5 U | 8.2 | 0.5 U |
| H1-6/9488 | 26-Mar-99 | 0.5 U | 10 | 0.5 U |
| H1-6/9488 | 29-Apr-99 | 0.5 U | 5.9 | 0.5 U |
| H1-6/9488 | 27-May-99 | 0.5 U | 5.5 | 0.5 U |
| H1-6/9488 | 24-Jun-99 | 0.5 U | 3.1 | 0.5 U |
| H1-6/9488 | 29-Jul-99 | 0.5 U | 10 | 0.5 U |
| H4-2/8526 | 23-Jan-97 | 0.8 | 18 | 0.5 U |
| H4-2/8526 | 20-Mar-97 | 0.6 | 8 | 0.5 U |
| H4-2/8526 | 25-Mar-97 | 0.5 U | 7 | 0.5 U |
| H4-2/8526 | 27-May-97 | 3.3 | 26 | 0.5 U |
| H4-2/8526 | 25-Jun-97 | 1.4 | 7.2 | 0.5 U |
| H4-2/8526 | 28-Jul-97 | 4.9 | 28 | 0.5 U |
| H4-2/8526 | 26-Aug-97 | 5.4 | 30 | 0.5 U |
| H4-2/8526 | 18-Sep-97 | 5.3 | 28 | 0.5 U |
| H4-2/8526 | 23-Oct-97 | 6.8 | 27 | 0.5 U |
| H4-2/8526 | 24-Nov-97 | 8.2 | 32 | 0.5 U |
| H4-2/8526 | 17-Dec-97 | 7 | 27 | 0.5 U |
| H4-2/8526 | 29-Jan-98 | 9.2 | 34 | 0.5 U |
| H4-2/8526 | 26-Feb-98 | 9.5 | 37 | 0.5 U |
| H4-2/8526 | 17-Mar-98 | 12 | 43 | 0.5 U |
| H4-2/8526 | 29-Apr-98 | 11 | 39 | 0.5 U |
| H4-2/8526 | 23-Jun-98 | 13 | 42 | 0.5 U |
| H4-2/8526 | 29-Jul-98 | 15 | 44 | 0.5 U |
| H4-2/8526 | 27-Aug-98 | 15 | 43 | 0.5 U |
| H4-2/8526 | 28-Sep-98 | 15 | 38 | 0.5 U |
| H4-2/8526 | 27-Oct-98 | 16 | 41 | 0.5 U |
| H4-2/8526 | 23-Nov-98 | 14 | 37 | 0.5 U |
| H4-2/8526 | 16-Dec-98 | 15 | 36 | 0.5 U |
| H4-2/8526 | 28-Jan-99 | 13 | 42 | 0.5 U |
| H4-2/8526 | 25-Feb-99 | 12 | 32 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| H4-2/8526 | 23-Mar-99 | 0.5 U | 11 | 0.5 U |
| H4-2/8526 | 29-Apr-99 | 10 | 27 | 0.5 U |
| H4-2/8526 | 27-May-99 | 12 | 22 | 0.5 U |
| H4-2/8526 | 23-Jun-99 | 13 | 22 | 0.5 U |
| H4-2/8526 | 29-Jul-99 | 15 | 44 | 0.5 U |
| H5-2/7561 | 23-Jan-97 | 4.1 | 55 | 0.5 U |
| H5-2/7561 | 26-Feb-97 | 4 | 9.2 | 0.5 U |
| H5-2/7561 | 24-Mar-97 | 6.2 | 81 | 0.5 U |
| H5-2/7561 | 28-Apr-97 | 4.2 | 60 | 0.5 U |
| H5-2/7561 | 28-May-97 | 6.6 | 79 | 0.5 U |
| H5-2/7561 | 18-Jun-97 | 4.1 | 53 | 0.5 U |
| H5-2/7561 | 28-Jul-97 | 5.7 | 72 | 0.5 U |
| H5-2/7561 | 26-Aug-97 | 6.2 | 76 | 0.5 U |
| H5-2/7561 | 18-Sep-97 | 4.3 | 49 | 0.5 U |
| H5-2/7561 | 23-Oct-97 | 5.9 | 70 | 0.5 U |
| H5-2/7561 | 24-Nov-97 | 5.8 | 68 | 0.5 U |
| H5-2/7561 | 17-Dec-97 | 4.5 | 51 | 0.5 U |
| H5-2/7561 | 29-Jan-98 | 5.5 | 64 | 0.5 U |
| H5-2/7561 | 26-Feb-98 | 6 | 71 | 0.5 U |
| H5-2/7561 | 23-Mar-98 | 7.3 | 81 | 0.5 U |
| H5-2/7561 | 29-Apr-98 | 6.2 | 68 | 0.5 U |
| H5-2/7561 | 26-May-98 | 7 | 76 | 0.5 U |
| H5-2/7561 | 23-Jun-98 | 6.8 | 73 | 0.5 U |
| H5-2/7561 | 30-Jul-98 | 6.9 | 66 | 0.5 U |
| H5-2/7561 | 27-Aug-98 | 8.8 | 74 | 0.5 U |
| H5-2/7561 | 28-Sep-98 | 8.4 | 65 | 0.5 U |
| H5-2/7561 | 27-Oct-98 | 9.2 | 80 | 0.5 U |
| H5-2/7561 | 23-Nov-98 | 8.6 | 81 | 0.5 U |
| H5-2/7561 | 18-Dec-98 | 7.9 | 71 | 0.5 U |
| H5-2/7561 | 27-Jan-99 | 7.8 | 93 | 0.5 U |
| H5-2/7561 | 25-Feb-99 | 7.3 | 69 | 0.5 U |
| H5-2/7561 | 24-Mar-99 | 8.5 | 87 | 0.5 U |
| H5-2/7561 | 29-Apr-99 | 8.4 | 69 | 0.5 U |
| H5-2/7561 | 27-May-99 | 9.1 | 54 | 0.5 U |
| H5-2/7561 | 24-Jun-99 | 7.4 | 41 | 0.5 U |
| H5-2/7561 | 29-Jul-99 | 6.6 | 49 | 0.5 U |
| H5-3/9212 | 23-Jan-97 | 1.7 | 5.2 | 0.5 U |
| H5-3/9212 | 26-Feb-97 | 5.9 | 77 | 0.5 U |
| H5-3/9212 | 24-Mar-97 | 3.2 | 13 | 0.5 U |
| H5-3/9212 | 28-Apr-97 | 2.5 | 6.4 | 0.5 U |
| H5-3/9212 | 28-May-97 | 2.9 | 10 | 0.5 U |
| H5-3/9212 | 18-Jun-97 | 2.2 | 4.9 | 0.5 U |
| H5-3/9212 | 28-Jul-97 | 3 | 9.7 | 0.5 U |
| H5-3/9212 | 26-Aug-97 | 3.2 | 11 | 0.5 U |
| H5-3/9212 | 18-Sep-97 | 3 | 6.8 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| H5-3/9212 | 23-Oct-97 | 3 | 8.6 | 0.5 U |
| H5-3/9212 | 24-Nov-97 | 3.8 | 10 | 0.5 U |
| H5-3/9212 | 17-Dec-97 | 3.1 | 7.9 | 0.5 U |
| H5-3/9212 | 29-Jan-98 | 3.7 | 9.1 | 0.5 U |
| H5-3/9212 | 26-Feb-98 | 3.7 | 11 | 0.5 U |
| H5-3/9212 | 23-Mar-98 | 5.1 | 13 | 0.5 U |
| H5-3/9212 | 29-Apr-98 | 4.8 | 11 | 0.5 U |
| H5-3/9212 | 26-May-98 | 4.6 | 11 | 0.5 U |
| H5-3/9212 | 23-Jun-98 | 5.5 | 12 | 0.5 U |
| H5-3/9212 | 30-Jul-98 | 6.4 | 9.8 | 0.5 U |
| H5-3/9212 | 27-Aug-98 | 5.8 | 12 | 0.5 U |
| H5-3/9212 | 28-Sep-98 | 6.9 | 11 | 0.5 U |
| H5-3/9212 | 27-Oct-98 | 7.3 | 15 | 0.5 U |
| H5-3/9212 | 23-Nov-98 | 6.3 | 12 | 0.5 U |
| H5-3/9212 | 18-Dec-98 | 5 | 10 | 0.5 U |
| H5-3/9212 | 27-Jan-99 | 6.8 | 16 | 0.5 U |
| H5-3/9212 | 25-Feb-99 | 5.6 | 11 | 0.5 U |
| H5-3/9212 | 24-Mar-99 | 6.4 | 15 | 0.5 U |
| H5-3/9212 | 29-Apr-99 | 5.3 | 8.4 | 0.5 U |
| H5-3/9212 | 27-May-99 | 7.8 | 9 | 0.5 U |
| H5-3/9212 | 24-Jun-99 | 6.7 | 5.8 | 0.5 U |
| H5-3/9212 | 29-Jul-99 | 8.4 | 9.7 | 0.5 U |
| H6-1/3953 | 20-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-1/3953 | 06-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-1/3953 | 22-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-1/3953 | 15-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 20-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 06-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 23-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 15-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 17-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 17-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 22-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 15-Dec-98 | 0.5 U | 0.5 U | 0.5 U |
| H6-2/3878 | 11-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 25-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 09-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 22-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 18-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 27-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 25-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 28-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 15-Dec-98 | 0.5 U | 0.5 U | 0.5 U |
| H7-1/6190 | 28-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| H8-1/6192 | 27-Feb-97 | 71 | 1.6 | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| H8-1/6192 | 25-Mar-97 | 110 | 2.6 | 0.5 U |
| H8-1/6192 | 22-Apr-97 | 73 | 1.3 | 0.5 U |
| H8-1/6192 | 27-May-97 | 110 | 2.5 | 0.5 U |
| H8-1/6192 | 25-Jun-97 | 91 | 2 | 0.5 U |
| H8-1/6192 | 29-Jul-97 | 100 | 2.4 | 0.5 U |
| H8-1/6192 | 27-Aug-97 | 88 | 1.8 | 0.5 U |
| H8-1/6192 | 25-Feb-98 | 37 | 0.5 U | 0.5 U |
| H8-1/6192 | 11-Mar-98 | 42 | 0.6 | 0.5 U |
| H8-1/6192 | 26-Mar-98 | 29 | 0.5 U | 0.5 U |
| H8-1/6192 | 29-Apr-98 | 52 | 0.8 | 0.5 U |
| H8-1/6192 | 29-May-98 | 91 | 0.9 | 0.5 U |
| H8-1/6192 | 24-Jun-98 | 81 | 1.6 | 0.5 U |
| H8-1/6192 | 30-Jul-98 | 84 | 1.9 | 0.5 U |
| H8-1/6192 | 27-Aug-98 | 72 | 1 | 0.5 U |
| H8-1/6192 | 28-Sep-98 | 83 | 3 | 0.5 U |
| H8-1/6192 | 27-Oct-98 | 91 | 2 | 0.5 U |
| H8-1/6192 | 23-Nov-98 | 94 | 2.3 | 0.5 U |
| H8-1/6192 | 16-Dec-98 | 90 | 2 | 0.5 U |
| H8-1/6192 | 27-Jan-99 | 89 | 1.6 | 0.5 U |
| H8-1/6192 | 25-Feb-99 | 82 | 1.6 | 0.5 U |
| H8-1/6192 | 25-Mar-99 | 78 | 1.7 | 0.5 U |
| H8-1/6192 | 28-Apr-99 | 57 | 0.8 | 0.5 U |
| H8-1/6192 | 27-May-99 | 79 | 1 | 0.5 U |
| H8-1/6192 | 23-Jun-99 | 84 | 1.1 | 0.5 U |
| H8-1/6192 | 29-Jul-99 | 71 | 1.7 | 0.5 U |
| H8-3/9180 | 27-Feb-97 | 19 | 0.5 U | 0.5 U |
| H8-3/9180 | 25-Mar-97 | 25 | 0.5 U | 0.5 U |
| H8-3/9180 | 22-Apr-97 | 21 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-May-97 | 26 | 0.5 U | 0.5 U |
| H8-3/9180 | 25-Jun-97 | 24 | 0.5 U | 0.5 U |
| H8-3/9180 | 29-Jul-97 | 22 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-Aug-97 | 24 | 0.5 U | 0.5 U |
| H8-3/9180 | 23-Sep-97 | 6.8 | 0.5 U | 0.5 U |
| H8-3/9180 | 25-Feb-98 | 2 | 0.5 U | 0.5 U |
| H8-3/9180 | 26-Mar-98 | 1.1 | 0.5 U | 0.5 U |
| H8-3/9180 | 29-Apr-98 | 12 | 0.5 U | 0.5 U |
| H8-3/9180 | 29-May-98 | 18 | 0.5 U | 0.5 U |
| H8-3/9180 | 24-Jun-98 | 19 | 0.5 U | 0.5 U |
| H8-3/9180 | 28-Jul-98 | 19 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-Aug-98 | 18 | 0.5 U | 0.5 U |
| H8-3/9180 | 28-Sep-98 | 19 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-Oct-98 | 20 | 0.5 U | 0.5 U |
| H8-3/9180 | 23-Nov-98 | 18 | 0.5 U | 0.5 U |
| H8-3/9180 | 16-Dec-98 | 14 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-Jan-99 | 15 | 0.5 U | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene µg/L</i> | <i>Trichloroethene µg/L</i> | <i>Vinyl Chloride µg/L</i> |
|-----------------|-------------|-----------------------------------|---------------------------------|--------------------------------|
| H8-3/9180 | 25-Feb-99 | 1.7 | 0.5 U | 0.5 U |
| H8-3/9180 | 25-Mar-99 | 15 | 0.5 U | 0.5 U |
| H8-3/9180 | 28-Apr-99 | 13 | 0.5 U | 0.5 U |
| H8-3/9180 | 27-May-99 | 20 | 0.5 U | 0.5 U |
| H8-3/9180 | 23-Jun-99 | 17 | 0.5 U | 0.5 U |
| H8-3/9180 | 29-Jul-99 | 17 | 0.5 | 0.5 U |
| H9-1/8778 | 19-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 06-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 15-Sep-97 | 0.5 U | 0.5 | 0.5 U |
| H9-1/8778 | 11-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 16-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 22-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 15-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 26-May-99 | 0.5 U | 0.5 U | 0.5 U |
| H9-1/8778 | 13-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 19-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 06-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 15-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 11-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 16-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 22-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 15-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 26-May-99 | 0.5 U | 0.5 U | 0.5 U |
| H9-2/8779 | 13-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| H9-3/10208 | 19-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-3/10208 | 11-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| H9-3/10208 | 16-Mar-98 | 0.5 U | 1 | 0.5 U |
| H9-3/10208 | 22-Jun-98 | 0.5 U | 2 | 0.5 U |
| H9-3/10208 | 15-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| H9-3/10208 | 26-May-99 | 0.5 U | 1.9 | 0.5 U |
| H9-3/10208 | 13-Jul-99 | 0.5 U | 3 | 0.5 U |
| L5A/7076 | 07-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 02-Dec-97 | 1 | 0.5 U | 0.5 U |
| L5A/7076 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| L5A/7076 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 16-Jan-97 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 01-Dec-97 | 0.5 U | 0.5 U | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| L8A/7523 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| L8A/7523 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-10977 | 15-Jul-88 | 0.1 U | 0.1 U | |
| N-10977 | 14-Jul-89 | 0.1 U | 0.1 U | |
| N-10977 | 02-Jan-91 | 0.1 U | 0.1 U | 0.1 U |
| N-10977 | 27-Dec-91 | 0.1 U | 0.1 U | 0.1 U |
| N-10977 | 16-Oct-92 | 0.1 U | 0.1 U | 0.1 U |
| N-10977 | 15-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-10977 | 18-May-95 | 1.3 | 0.1 U | 0.1 U |
| N-10977 | 13-Jul-98 | 1 U | 1 U | 1 U |
| N-11067 | 18-Jul-88 | 0.1 U | 0.1 U | |
| N-11067 | 14-Jul-89 | 0.1 U | 0.1 U | |
| N-11067 | 27-Dec-90 | 0.1 U | 0.1 U | 0.1 U |
| N-11067 | 16-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11067 | 19-Nov-96 | 1 | 0.1 U | 0.1 U |
| N-11457 | 01-Nov-89 | 0.1 U | 0.1 U | |
| N-11457 | 07-Dec-90 | 0.1 U | 0.1 U | 0.1 U |
| N-11457 | 17-Dec-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11457 | 06-Oct-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11457 | 23-May-94 | 0.1 U | 0.1 U | 0.1 U |
| N-11457 | 24-Jul-95 | 2.1 | 0.1 U | 0.1 U |
| N-11457 | 19-Feb-98 | 0.1 U | 0.1 U | 0.1 U |
| N-11458 | 16-Oct-89 | 0.1 U | 0.1 U | |
| N-11458 | 14-Nov-90 | 0.1 U | 0.1 U | 0.1 U |
| N-11458 | 22-Nov-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11458 | 13-Oct-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11458 | 24-Dec-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11458 | 10-May-95 | 2.8 | 0.1 U | 0.1 U |
| N-11458 | 20-Feb-98 | 0.1 U | 0.1 U | 0.1 U |
| N-11633 | 28-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11633 | 14-Oct-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11633 | 21-Dec-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11633 | 26-Jul-95 | 0.1 U | 0.1 U | 0.1 U |
| N-11633 | 29-Jan-98 | 0.1 U | 0.1 U | 0.1 U |
| N-11722 | 07-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11722 | 27-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11722 | 29-Sep-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11722 | 24-Jul-95 | 0.1 U | 0.1 U | 0.1 U |
| N-11722 | 17-Jul-98 | 1 U | 1 U | 1 U |
| N-11723 | 07-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11723 | 28-Aug-92 | 0.1 U | 0.1 U | 0.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-11723 | 29-Sep-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11723 | 22-May-95 | 2 | 0.1 U | 0.1 U |
| N-11723 | 20-Jan-99 | 1 U | 1 U | 1 U |
| N-11724 | 11-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11724 | 20-Nov-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11724 | 29-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11724 | 23-Aug-95 | 0.1 U | 0.1 U | 0.1 U |
| N-11724 | 05-Oct-98 | 1 U | 1 U | 1 U |
| N-11731 | 11-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-11731 | 18-Nov-92 | 0.1 U | 0.1 U | 0.1 U |
| N-11731 | 29-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-11731 | 19-May-95 | 0.7 | 0.1 U | 0.1 U |
| N-11731 | 15-Jul-98 | 1 U | 1 U | 1 U |
| N-1195 | 18-Nov-88 | 0.1 U | 0.1 U | |
| N-1195 | 08-Dec-89 | 0.1 U | 0.1 U | |
| N-1195 | 15-Oct-90 | 0.1 U | 0.1 U | 0.1 U |
| N-1195 | 25-Nov-91 | 0.1 U | 0.1 U | 0.1 U |
| N-1195 | 03-Oct-92 | 0.1 U | 0.1 U | 0.1 U |
| N-1195 | 27-Apr-93 | 0.1 U | 0.1 U | 0.1 U |
| N-1195 | 03-Nov-95 | 0.1 U | 0.1 U | 0.1 U |
| N-1195 | 03-Sep-98 | 1 U | 1 U | 1 U |
| N-1197 | 29-Jan-85 | 6.3 | 74.3 | |
| N-1197 | 27-Mar-85 | 3.9 | 31.5 | |
| N-1197 | 29-Jun-88 | 10.1 | 3 | |
| N-1197 | 08-Dec-89 | 51.6 | 2.8 | |
| N-1197 | 18-Apr-90 | 332 | 3.2 | |
| N-1197 | 08-Aug-91 | 446 | 9.8 | 0.1 U |
| N-1197 | 27-Jul-92 | 111 | 8 | 0.1 U |
| N-1197 | 06-Oct-93 | 7.3 | 4.3 | 0.1 U |
| N-1197 | 14-Nov-94 | 15.5 | 5.7 | 0.1 U |
| N-1197 | 16-Aug-96 | 5.9 | 0.1 U | 0.1 U |
| N-1197 | 02-Jun-99 | 9.2 | 2 | 1.1 U |
| N-1197 | 30-Jun-99 | 10.1 | 1.9 | 1.1 U |
| N-12250 | 08-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-12250 | 31-Oct-95 | 0.1 U | 0.1 U | 0.1 U |
| N-12250 | 09-Sep-98 | 1 U | 1 U | 1 U |
| N-1231 | 24-Feb-86 | 5.3 | 0.7 | |
| N-1231 | 06-Sep-89 | 6.4 | 0.1 U | |
| N-1231 | 26-Apr-90 | 8.9 | 0.5 | |
| N-1231 | 18-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-1231 | 30-Jul-92 | 10.9 | 0.1 U | 0.1 U |
| N-1231 | 18-Oct-93 | 5.9 | 0.1 U | 0.1 U |
| N-1231 | 14-Sep-94 | 10.3 | 0.4 | 0.1 U |
| N-1231 | 16-Aug-96 | 5.5 | 0.1 U | 0.1 U |
| N-1231 | 25-Nov-98 | 18.3 | 1 U | 1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-1232 | 18-Jul-88 | 0.1 U | 0.1 U | |
| N-1232 | 19-Jul-89 | 0.1 U | 0.1 U | |
| N-1232 | 30-Aug-90 | 0.1 U | 0.1 U | 0.1 U |
| N-1232 | 02-Aug-91 | 0.1 U | 0.1 U | 0.1 U |
| N-1232 | 07-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-1232 | 12-May-93 | 0.1 U | 0.1 U | 0.1 U |
| N-1232 | 27-Oct-95 | 0.1 U | 0.1 U | 0.1 U |
| N-1232 | 12-Jan-99 | 1 U | 1 U | 1 U |
| N-12560 | 07-Mar-97 | 1 | 0.5 U | 0.5 U |
| N-12560 | 16-Jun-97 | 2 | 0.5 U | 0.5 U |
| N-12560 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-12560 | 01-Dec-97 | 2 | 0.5 U | 0.5 U |
| N-12560 | 23-Mar-98 | 3 | 0.5 U | 0.5 U |
| N-12560 | 05-Jun-98 | 2 | 0.5 U | 0.5 U |
| N-12560 | 09-Sep-98 | 4 | 0.5 U | 0.5 U |
| N-12560 | 08-Oct-98 | 3 | 0.5 U | 0.5 U |
| N-12560 | 22-Jan-99 | 6 | 0.5 U | 0.5 U |
| N-12560 | 28-Jan-99 | 5 | 0.5 U | 0.5 U |
| N-12560 | 04-Feb-99 | 5 | 0.5 U | 0.5 U |
| N-4450 | 07-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 02-Dec-97 | 1 | 0.5 U | 0.5 U |
| N-4450 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 16-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| N-4450 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 07-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 01-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| N-5302 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 07-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 01-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-5303 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| N-5303 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 07-Mar-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 01-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 09-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 01-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-5304 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 07-Nov-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 13-Jan-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 26-Jan-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 10-Feb-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 03-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 07-Apr-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 12-May-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 04-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 08-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 04-Aug-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 03-Sep-98 | 0.5 U | 8.5 | 0.5 U |
| N-8004 | 01-Oct-98 | 0.5 U | 13 | 0.5 U |
| N-8004 | 29-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 23-Nov-98 | 0.5 U | 0.7 | 0.5 U |
| N-8004 | 02-Dec-98 | 0.5 U | 1.2 | 0.5 U |
| N-8004 | 05-Jan-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 18-Feb-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 16-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 30-Apr-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 19-May-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8004 | 19-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 16-Jan-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 16-Jun-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 02-Sep-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 01-Dec-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 23-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 05-Jun-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 08-Sep-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 08-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8279 | 03-Mar-99 | 0.5 U | 0.5 U | 0.5 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-8279 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8321 | 16-Jan-97 | 0.5 U | 0.5 | 0.5 U |
| N-8321 | 16-Jun-97 | 0.5 U | 1 | 0.5 U |
| N-8321 | 02-Sep-97 | 0.5 U | 1 | 0.5 U |
| N-8321 | 01-Dec-97 | 0.5 U | 1 | 0.5 U |
| N-8321 | 23-Mar-98 | 0.5 U | 1 | 0.5 U |
| N-8321 | 05-Jun-98 | 0.5 U | 1 | 0.5 U |
| N-8321 | 17-Sep-98 | 0.5 U | 1 | 0.5 U |
| N-8321 | 09-Oct-98 | 0.5 U | 1 | 0.5 U |
| N-8321 | 03-Mar-99 | 0.5 U | 1 | 0.5 U |
| N-8321 | 17-Jun-99 | 0.5 U | 2 | 0.5 U |
| N-8550 | 16-Apr-87 | 0.5 | 0.7 | |
| N-8550 | 31-May-88 | 0.1 U | 0.5 | |
| N-8550 | 21-Dec-89 | 0.1 U | 0.1 U | |
| N-8550 | 10-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-8550 | 28-Oct-93 | 0.1 U | 0.1 U | 0.1 U |
| N-8550 | 15-Sep-94 | 1.9 | 1.5 | 0.1 U |
| N-8550 | 21-Jan-97 | 0.1 U | 0.8 | 0.1 U |
| N-8550 | 07-Oct-98 | 1.9 | 2.1 | 1 U |
| N-8767 | 19-Feb-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 15-Apr-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 08-Jul-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 08-Oct-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 30-Apr-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 08-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 24-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 01-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 13-Jan-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 14-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8767 | 20-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 19-Feb-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 15-Apr-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 08-Jul-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 08-Oct-97 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 30-Mar-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 30-Apr-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 08-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 01-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 13-Jan-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 14-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8768 | 20-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| N-8888 | 28-Jan-85 | 4.8 | 6.6 | |
| N-8888 | 02-Nov-89 | 0.1 U | 0.1 U | |
| N-8888 | 15-Nov-90 | 0.1 U | 0.1 U | 0.1 U |
| N-8888 | 26-Nov-91 | 0.1 U | 0.1 U | 0.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-8888 | 12-Aug-92 | 18.3 | 1 U | 1 U |
| N-9079 | 10-Jul-89 | 0.1 U | 1.2 | |
| N-9079 | 07-Jun-90 | 0.1 U | 2.7 | |
| N-9079 | 07-Aug-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9079 | 27-Jul-92 | 2 | 0.1 U | 0.1 U |
| N-9079 | 07-Oct-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9079 | 14-Sep-94 | 2.6 | 1.5 | 0.1 U |
| N-9079 | 16-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9079 | 03-Sep-98 | 1 U | 1 U | 1 U |
| N-9088 | 16-May-88 | 0.1 U | 0.1 U | |
| N-9088 | 19-Apr-89 | 0.1 U | 0.1 U | |
| N-9088 | 17-Jul-89 | 1.1 | 0.1 U | |
| N-9088 | 09-Jan-90 | 0.1 U | 0.1 U | |
| N-9088 | 28-Jan-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9088 | 14-Feb-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9088 | 15-Jan-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9088 | 29-Dec-94 | 0.1 U | 0.1 U | 0.1 U |
| N-9088 | 11-Dec-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9088 | 05-Jan-98 | 0.1 U | 0.1 U | 0.1 U |
| N-9591 | 19-Feb-97 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 15-Apr-97 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 08-Jul-97 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 08-Oct-97 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 13-Jan-98 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 30-Apr-98 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 08-Jul-98 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 01-Oct-98 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 23-Mar-99 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 17-Jun-99 | 0.5 U | 0.5 U | 0.5 U |
| N-9591 | 20-Jul-99 | 0.5 U | 0.5 U | 0.5 U |
| N-9654 | 14-Apr-87 | 1.9 | 0.2 | |
| N-9654 | 13-May-88 | 0.1 U | 0.1 U | |
| N-9654 | 25-May-89 | 0.1 U | 0.1 U | |
| N-9654 | 09-Jan-90 | 0.1 U | 0.1 U | |
| N-9654 | 28-Jan-91 | 0.1 U | 1 | 0.1 U |
| N-9654 | 14-Feb-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9654 | 21-Jan-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9654 | 29-Dec-94 | 0.1 U | 0.1 U | 0.1 U |
| N-9654 | 19-Nov-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9654 | 06-May-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9654 | 15-Jun-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9661 | 11-May-88 | 0.1 U | 0.1 U | |
| N-9661 | 06-Apr-89 | 0.1 U | 0.1 U | |
| N-9661 | 08-Jan-90 | 0.1 U | 0.1 U | |
| N-9661 | 24-Jan-91 | 0.1 U | 0.1 U | 0.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-9661 | 14-Feb-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9661 | 21-Jan-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9661 | 26-Jan-95 | 0.1 U | 0.1 U | 0.1 U |
| N-9661 | 20-Nov-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9661 | 03-May-99 | 1 U | 1 U | 1 U |
| N-9667 | 17-May-88 | 0.1 U | 0.1 U | |
| N-9667 | 13-Jul-89 | 1.5 | 0.1 U | |
| N-9667 | 22-Feb-90 | 0.1 U | 0.1 U | |
| N-9667 | 08-Apr-91 | 1.1 | 0.1 U | 0.1 U |
| N-9667 | 27-Apr-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9667 | 16-Feb-93 | 1.1 | 0.3 | 0.1 U |
| N-9667 | 17-Jan-95 | 0.5 | 0.1 U | 0.1 U |
| N-9667 | 19-Nov-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9667 | 24-Jul-98 | 1 U | 1 U | 1 U |
| N-9667 | 26-Jul-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9917 | 29-Jan-85 | 1.5 | 1 | |
| N-9917 | 27-Mar-85 | 1.3 | | |
| N-9917 | 09-Jun-88 | 0.1 U | 0.1 U | |
| N-9917 | 10-Jul-89 | 0.1 U | 0.1 U | |
| N-9917 | 07-Jun-90 | 0.1 U | 0.1 U | |
| N-9917 | 15-Jul-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9917 | 27-Jul-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9917 | 06-Oct-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9917 | 30-May-95 | 5.3 | 0.1 U | 0.1 U |
| N-9917 | 10-Sep-98 | 1 U | 1 U | 1 U |
| N-9918 | 14-Apr-87 | 2.9 | | |
| N-9918 | 27-May-88 | 0.1 U | 0.1 U | |
| N-9918 | 10-Jul-89 | 0.1 U | 0.1 U | |
| N-9918 | 19-Jun-90 | 0.1 U | 0.1 U | |
| N-9918 | 15-Jul-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9918 | 27-Jul-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9918 | 06-Oct-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9918 | 15-Sep-94 | 1.2 | 0.1 U | 0.1 U |
| N-9918 | 15-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9918 | 24-May-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9918 | 22-Jun-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9919 | 27-Mar-85 | 708 | 5.7 | |
| N-9919 | 06-Feb-87 | 258 | 5.2 | |
| N-9919 | 31-May-88 | 47.8 | 3.3 | |
| N-9919 | 14-Dec-89 | 48 | 0.9 | |
| N-9919 | 13-Nov-90 | 52.2 | 0.1 U | 0.1 U |
| N-9919 | 25-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9919 | 10-Aug-92 | 20.9 | 0.1 U | 0.1 U |
| N-9919 | 28-Oct-93 | 11.9 | 0.1 U | 0.1 U |
| N-9919 | 14-Sep-94 | 25.2 | 0.5 | 0.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-9919 | 16-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9919 | 18-May-99 | 16.9 | 1.7 U | 1.1 U |
| N-9919 | 22-Jun-99 | 26 | 1.7 U | 1.1 U |
| N-9920 | 29-Jan-85 | 3.9 | 1.3 | |
| N-9920 | 14-Jul-88 | 0.1 U | 0.1 U | |
| N-9920 | 15-Nov-89 | 0.1 U | 0.1 U | |
| N-9920 | 03-Jan-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9920 | 08-Dec-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9920 | 14-Jun-95 | 5.7 | 0.1 U | 0.1 U |
| N-9920 | 10-Nov-95 | 0.1 U | 0.1 U | 0.1 U |
| N-9920 | 12-Jan-99 | 1 U | 1 U | 1 U |
| N-9921 | 26-Feb-86 | 1.2 | 32.9 | |
| N-9921 | 11-Feb-87 | 5.8 | 80.3 | |
| N-9921 | 27-May-88 | 3 | 31.6 | |
| N-9921 | 06-Jul-89 | 1.4 | 59.6 | |
| N-9921 | 07-Jun-90 | 0.1 U | 3.5 | 0.1 U |
| N-9921 | 21-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9921 | 07-Aug-92 | 0.1 U | 5.8 | 0.1 U |
| N-9921 | 28-Oct-93 | 0.1 U | 3.7 | 0.1 U |
| N-9921 | 07-Nov-94 | 1.9 | 9.4 | 0.1 U |
| N-9921 | 12-Dec-96 | 0.1 U | 3.9 | 0.1 U |
| N-9921 | 18-May-99 | 1.2 U | 20.3 | 1.1 U |
| N-9922 | 24-Apr-87 | 14.8 | | |
| N-9922 | 20-Jul-88 | 33.8 | 0.1 U | |
| N-9922 | 07-Jul-89 | 33.2 | 0.1 U | |
| N-9922 | 19-Jun-90 | 65.5 | 0.1 U | |
| N-9922 | 15-Jul-91 | 44.1 | 0.1 U | 0.1 U |
| N-9922 | 27-Jul-92 | 22.1 | 0.1 U | 0.1 U |
| N-9922 | 06-Oct-93 | 5 | 0.1 U | 0.1 U |
| N-9922 | 14-Sep-94 | 21.9 | 0.6 | 0.1 U |
| N-9922 | 12-Dec-96 | 45.2 | 0.1 U | 0.1 U |
| N-9922 | 18-May-99 | 14.5 | 1.7 U | 1.1 U |
| N-9924 | 14-Apr-87 | 0.5 | | |
| N-9924 | 03-Jan-89 | 0.1 U | 0.1 U | |
| N-9924 | 20-Apr-90 | 0.1 U | 0.1 U | |
| N-9924 | 08-Apr-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9924 | 27-Apr-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9924 | 16-Feb-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9924 | 17-Jan-95 | 0.1 U | 0.1 U | 0.1 U |
| N-9924 | 19-Nov-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9924 | 24-Jul-98 | 1 U | 1 U | 1 U |
| N-9925 | 21-Apr-88 | 0.1 U | 0.5 | |
| N-9925 | 26-May-89 | 0.1 U | 0.1 U | |
| N-9925 | 20-Jun-90 | 0.1 U | 0.1 U | |
| N-9925 | 24-Jun-91 | 0.1 U | 0.1 U | 0.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-9925 | 10-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9925 | 12-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9925 | 16-Sep-94 | 1.1 | 0.2 | 0.1 U |
| N-9925 | 19-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9925 | 18-May-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9927 | 28-Jan-85 | 2.2 | 0.2 | |
| N-9927 | 22-Jul-88 | 0.1 U | 0.1 U | |
| N-9927 | 30-Oct-89 | 0.1 U | 0.1 U | |
| N-9927 | 13-Nov-90 | 0.1 U | 0.1 U | 0.1 U |
| N-9927 | 25-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9927 | 11-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9927 | 28-Oct-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9927 | 09-Nov-95 | 0.1 U | 0.1 U | 0.1 U |
| N-9927 | 26-Jan-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9928 | 14-Apr-87 | 0.3 | | |
| N-9928 | 27-May-88 | 0.1 U | 0.1 U | |
| N-9928 | 06-Jul-89 | 0.1 U | 0.1 U | |
| N-9928 | 07-Jun-90 | 0.1 U | 0.1 U | |
| N-9928 | 03-May-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9928 | 02-Jun-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9928 | 27-Apr-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9928 | 29-Jun-95 | 0.1 U | 0.1 U | 0.1 U |
| N-9928 | 12-Jan-99 | 1 U | 1 U | 1 U |
| N-9929 | 14-Dec-89 | 0.1 U | 0.1 U | |
| N-9929 | 27-Dec-90 | 0.1 U | 0.1 U | 0.1 U |
| N-9929 | 15-Nov-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9929 | 06-Jul-99 | 1.2 U | 1.7 U | 1.1 U |
| N-9931 | 18-Jul-88 | 0.1 U | 0.1 U | |
| N-9931 | 23-Oct-89 | 0.1 U | 0.1 U | |
| N-9931 | 07-Jan-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9931 | 10-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9931 | 11-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9931 | 01-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9931 | 14-Nov-94 | 1.7 | 0.1 U | 0.1 U |
| N-9931 | 21-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 25-Feb-86 | 0.9 | | |
| N-9932 | 14-Jul-88 | 4 | 0.1 U | |
| N-9932 | 19-Jul-89 | 3 | 0.1 U | |
| N-9932 | 12-Oct-90 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 25-Jun-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 10-Aug-92 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 01-Nov-93 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 13-Sep-94 | 1 | 0.2 | 0.1 U |
| N-9932 | 21-Aug-96 | 0.1 U | 0.1 U | 0.1 U |
| N-9932 | 07-May-99 | 1.2 U | 1.7 U | 1.1 U |

APPENDIX E

GROUNDWATER CONCENTRATIONS
OBTAINED FROM NASSAU COUNTY

| <i>Location</i> | <i>Date</i> | <i>Tetrachloroethene</i> <i>µg/L</i> | <i>Trichloroethene</i> <i>µg/L</i> | <i>Vinyl Chloride</i> <i>µg/L</i> |
|-----------------|-------------|---|---------------------------------------|--------------------------------------|
| N-9938 | 25-Mar-85 | 31.8 | 370 | |
| N-9938 | 04-Feb-87 | 284 | 331 | |
| N-9938 | 21-Apr-88 | 82.9 | 379 | |
| N-9938 | 13-Oct-88 | 160 | 346 | |
| N-9938 | 07-Jul-89 | 181 | 267 | |
| N-9938 | 28-Nov-89 | 267 | 307 | |
| N-9938 | 25-Apr-90 | 144 | 164 | |
| N-9938 | 15-Jul-91 | 100 | 70.8 | 0.1 U |
| N-9938 | 10-Aug-92 | 83.7 | 126 | 0.1 U |
| N-9938 | 10-Dec-93 | 32.2 | 19.1 | 0.1 U |
| N-9938 | 15-Nov-94 | 53.3 | 75.6 | 0.1 U |
| N-9938 | 20-Aug-96 | 35.6 | 29 | 0.1 U |
| N-9939 | 25-Mar-85 | 24.3 | 4.1 | |
| N-9939 | 04-Feb-87 | 26.8 | 12.2 | |
| N-9939 | 21-Apr-88 | 8 | 1.2 | |
| N-9939 | 26-May-89 | 2.7 | 0.1 U | |
| N-9939 | 19-Jun-90 | 3.5 | 0.7 | |
| N-9939 | 15-Jul-91 | 0.1 U | 0.1 U | 0.1 U |
| N-9939 | 27-Jul-92 | 3.5 | 2 | 0.1 U |
| N-9939 | 07-Oct-93 | 5.8 | 2.1 | 0.1 U |
| N-9939 | 07-Nov-94 | 10.4 | 2.1 | 0.1 U |
| N-9939 | 20-Aug-96 | 7 | 0.1 U | 0.1 U |
| N-9981 | 19-Jul-88 | 1.1 | 0.1 U | |
| N-9981 | 15-Nov-89 | 0.9 | 0.1 U | |
| N-9981 | 30-Nov-98 | 1 U | 1 U | 1 U |

Rationale for Calculating the Present-Worth Cost
for
Alternatives 1, 2 and 3

Alternative 1

$$PV = AC \times ((1 - (1 + i\%)^{-n}) / i\%)$$

where PV = present value

AC = annual O&M and monitoring cost (\$6,000)

i = discount rate (7%)

n = term (30 years)

$$PV = \$6,000 \times ((1 - (1 + 0.07)^{-30}) / 0.07) = \$74,000$$

| | |
|---------------|---|
| Capital Cost: | 0 |
|---------------|---|

| | |
|---|----------|
| Present Value of O&M and Monitoring Cost: | \$74,000 |
|---|----------|

| | |
|----------------------------------|-----------------|
| Total Present-Worth Cost: | \$74,000 |
|----------------------------------|-----------------|

Alternative 2

$$PV = AC \times ((1 - (1 + i\%)^{-n}) / i\%)$$

where PV = present value

AC = annual O&M and monitoring cost (\$722,000)

i = discount rate (7%)

n = term (30 years)

$$PV = \$722,000 \times ((1 - (1 + 0.07)^{-30}) / 0.07) = \$9,000,000$$

| | |
|---------------|-------------|
| Capital Cost: | \$4,195,000 |
|---------------|-------------|

| | |
|---|-------------|
| Present Value of O&M and Monitoring Cost: | \$9,000,000 |
|---|-------------|

| | |
|----------------------------------|---------------------|
| Total Present-Worth Cost: | \$13,200,000 |
|----------------------------------|---------------------|

Alternative 3

$$PV = AC \times ((1 - (1 + i\%)^{-n}) / i\%)$$

where PV = present value

AC = annual O&M and monitoring cost (\$319,000)
i = discount rate (7%)
n = term (12 years)

$$PV = \$319,000 \times ((1 - (1 + 0.07)^{-12}) / 0.07) = \$2,500,000$$

| | |
|---|--------------------|
| Capital Cost: | \$1,260,000 |
| Present Value of O&M and Monitoring Cost: | <u>\$2,500,000</u> |
| Total Present-Worth Cost: | \$3,760,000 |

Total Present-Worth Cost for Alternative 3 rounded to: \$3,800,000

Rationale for Calculating the Monitoring Cost for Alternative 1

Total samples to be collected semianually: 4

Total samples to be collected annually: 8

Estimated cost for analyzing 8 samples annually: 8 samples @ a rate of \$500.00/sample

$$8 \times 500.00 = \$ 3000.00$$

Estimated labor cost for collecting samples in two events: \$ 3000.00

Annual Monitoring cost for Alternative: \$ 6000.00